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Study of High-Speed Civil Transports

Summary

Douglas Aircraft Company
New Commercial Programs
Long Beach, California

Prepared for
Langley Research Center
under Contract NAS1-18378

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Space Administration
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CONTENTS

FIGURES

GLOSSARY

ADP	Advanced Ducted Prop
ADS	Automated Dependent Surveillance
AERA	Automatic En Route ATC
Al	aluminum
Al MMC	aluminum metal matrix composites
Alt	altitude
ASM	available seat-mile
ASNM	available seat-nautical mile
AST	Advanced Supersonic Transport
ATA	Air Transport Association
ATC	air traffic control
ATR	air turboramjet
CAB	Civil Aeronautics Board
CCTV	closed-circuit television
CFD	computational fluid dynamics
cg	center of gravity
CR	cruise
dB	decibel
dB(A)	unit of A-weighted noise level
DOC	direct operating cost
EINOx	NOx Emissions Index (lb NOx per 1,000 lb fuel burned)
EPNdB	Effective Perceived Noise Level in decibels
EPNL	Effective Perceived Noise Level
F	fahrenheit
FAA	Federal Aviation Administration
FAD	Fuel Advisory Departures
FAR	Federal Airworthiness Regulations
FC	first class
FEM	finite element model
g	acceleration of gravity
GE	General Electric Aircraft Engines
GNP	gross national product
GPS	Global Positioning System
Graphite/HFC, TZM	Graphite Fibers with Hafnium Carbide Matrix Composites, Molybdenum Titanium Zirconium alloy
GW	gross weight
HR	hour
HSCT	High-Speed Civil Transport
HSPA	high-speed propulsion assessment
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IN.	inches
I_{SP}	specific impulse
IVP	inverted velocity profile
L_{ce}	C-Weighted Sound Exposure Level in decibels
lb	pounds
LC_{dn}	Day-Night Average C-Weighted Sound Exposure Level
LFC	laminar-flow control
LH_2	liquid hydrogen
LNG	liquid methane gas
M	Mach number
MDBOOM	Sonic Boom Analysis, Douglas Aircraft

GLOSSARY
(Continued)

MIT	Massachusetts Institute of Technology
MMLI	modularized multilayer insulation
MMC	metal matrix composite
MTOGW	maximum takeoff gross weight
NAS Plan	National Airspace System Plan
NASA	National Aeronautics and Space Administration
NASP	National AeroSpace Plane
NMI	nautical mile
NO_X	oxides of nitrogen (all species)
OEW	operator's empty weight
P&W	Pratt & Whitney
PC	polymetric composites
PEEK	poly ether-ether ketone
PLdB	Steven Mark VII Perceived Level of Loudness in decibels
PM/PV	premixed, prevaporized
PMR	polyimide resin
psf	lb/ft^2
R&T	research and technology
RB/QQ	rich burn-quick quench
RPM	revenue passenger mile
RSR	rapidly solidification rate
S_W	wing area
SCAR	Supersonic Cruise Aircraft Research
SCR	Supersonic Cruise Research
SCS	silicon carbide system
SERN	single expansion ramp nozzle
SFC	specific fuel consumption
SPF/DB	super-plastically formed, diffusion bonded
ST	statute mile
T	temperature
TAD	technology availability date
TD Ni Cr	thoria dispersion nickel chrome
Ti	titanium
Ti MMC	titanium metal matrix composite
TOGW	takeoff gross weight
TPS	thermal protection system
TSJF	thermally stable jet fuel
T/W	(engine) thrust/weight ratio
USSR	Union of Soviet Socialist Republics
VABI	variable area bypass injector
VCE	variable cycle engine
VCHJ	variable cycle hypersonic jet
VSCE	variable stream control engine
τ	slenderness factor = volume/(wing area)$^{3/2}$
Δp	overpressure

FOREWORD

The High-Speed Civil Transport (HSCT) study integrated results of technical and economic analysis of various aircraft to determine their commercial potential and corresponding technology requirements. This extended beyond previous primarily technology-oriented activities such as the Advanced Supersonic Transport (AST) and Supersonic Cruise Research (SCR), and included consideration of ongoing technology developments of the National AeroSpace Plane (NASP) program. Appropriate technologies were assessed in terms of the commercial value of HSCT aircraft.

Work was accomplished by Douglas Aircraft Company in Long Beach, California. This work commenced in October 1986 at the direction of the NASA Langley Research Center, Hampton, Virginia, and was jointly funded under Contract NAS1-18378.

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SUMMARY

A systems study to identify the economic potential for a high-speed commercial transport has considered technology, market characteristics, airport infrastructure, and environmental issues. Market forecasts indicate a need for HSCT service in the 2000/2010 time frame conditioned on economic viability and environmental acceptability. Design requirements focused on a 300-passenger, three-class service, and 6,500-nautical-mile range based on the accelerated growth of the Pacific region. Compatibility with existing airports was an assumed requirement. Mach numbers between 2 and 25 were examined in conjunction with the appropriate propulsion systems, fuels, structural materials, and thermal management systems. Aircraft productivity was a key parameter with aircraft worth, in comparison to aircraft price, being the airline-oriented figure of merit. Aircraft screening led to determination that Mach 3.2 (TSJF) would have superior characteristics to Mach 5.0 (LNG) and the recommendation that the next generation high-speed commercial transport aircraft use a kerosene fuel. The sensitivity of aircraft performance and economics to environmental constraints (e.g., sonic boom, engine emissions, and airport/community noise) was identified together with key technologies. In all, current technology is not adequate to produce viable HSCTs for the world marketplace. Technology advancements must be accomplished to meet environmental requirements (these requirements are as yet undetermined for sonic boom and engine emissions). High priority is assigned to aircraft gross weight reduction which benefits both economics and environmental aspects. Specific technology requirements have been identified, which was the prime objective of this study. National economic benefits are projected.

INTRODUCTION

Commercial aviation has grown to become a mature, highly competitive, worldwide industry. The growth in air travel is projected to continue well into the 21st century with increasing demand for more efficient aircraft and increasing focus on environmental compatibility. Manufacture of commercial aircraft is a significant element of the U.S. economy and a major contributor to the balance of trade. In 1985, the White House Office of Science and Technology fostered long-range goals for continued U.S. leadership in aeronautics. In 1986, NASA commissioned this 2-year High-Speed Civil Transport (HSCT) study of supersonic transport viability and technology requirements to meet these goals.

This report is a summary of that work conducted by the Douglas Aircraft Company under contract NAS1-18378. This study was initially of broad perspective and then focused on the critical aspects of the best HSCT concepts with the overall goal of no measurable impact on the environment. At the outset, cruise speeds ranging from Mach 2 to 25 were considered. Major elements included (1) vehicle technology assessment based on all the traditional disciplines and their integration into vehicle concepts, (2) evaluations of HSCT operating and production costs, and comparisons of vehicle price and worth, and (3) definition and assessment of the more promising concepts in more detail. In addition, special factors such as airport infrastructure, fuel technology, and the environmental concerns for sonic boom, community noise, and engine emissions were included.

Engine data were obtained through subcontracts to Aerojet TechSystems, General Electric Aircraft Engines, and Pratt & Whitney (P&W). In addition, subcontracts have provided expertise in such areas as air traffic control, cryogenic fuels technology, airport facilities development, energy analysis, sonic-boom technology, and market-related issues (such as schedules and passenger value-of-time). Airline viewpoints have been incorporated from both U.S. and overseas airlines on an ad hoc basis.

The study was organized into three phases, as shown in Figure 1 with Phase I constituting a broad, goal-oriented screening. At its conclusion, concepts utilizing hydrogen fuel were eliminated due to their relative low economic performance caused by hydrogen fuel prices. Phase II focused on Mach 2.2, Mach 3.2, and Mach 5.0 without environmental restrictions for supersonic cruise over land, community noise, or accountability for engine emissions/atmospheric interactions; this established baselines for follow-on evaluations. Concepts with cruise speeds of Mach 3.2 and Mach 5.0 were selected for more detailed study in Phase III with the Mach 3.2 concept utilizing thermally stable jet fuel (TSJF) and the Mach 5.0 liquid methane (LNG). The focus of Phase III was environmental acceptability. Since research may be based on the results of this work, it was considered imperative to assess Mach 3.2 and Mach 5.0 reflecting significantly different speeds and cruise altitude. Phase III included integration of NASP technologies to access contributions from this ongoing program to civil aviation.

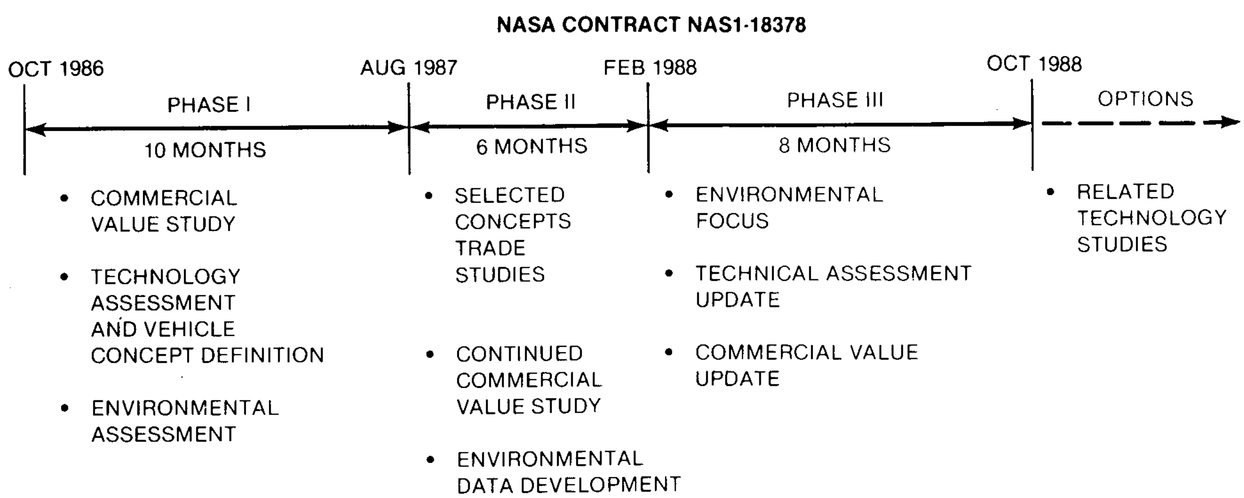


FIGURE 1. HIGH-SPEED CIVIL TRANSPORT STUDY

Environmental acceptability and economic viability are key to technology requirements which will significantly influence U.S. industry's eventual decision to go ahead on an HSCT development and production program. Douglas considers resolution to the environmental issues to be of first-order importance with selection of a specific cruise Mach number a part of the HSCT design process.

MARKET ANALYSIS

Assessment of the commercial value of the HSCT requires a comparison between its economic worth and cost-based price. This includes the following:

- Traffic demand
- Market share
- Passenger value of time
- Productivity
- Aircraft scheduling
- Fleet sizes
- Passenger revenue
- Operating costs
- Cash flow
- Airline return on investment
- Tax law
- Useful life
- Quantity
- Development cost
- Recurring production cost
- Manufacturers' return on investment

The overall evaluation process, specially designed economic and operational modes, and supporting data were the products of this study. Frequent consultation with airlines, including Northwest, Federal Express, American, Delta, United, Pan Am, Japan Air Lines, Alitalia, and British Airways, provided invaluable exchanges regarding traffic projections, schedules, economic parameters, and related matters. Expert consultation on such issues as aircraft scheduling, utilization, and productivity as well as passenger value of time was received from Massachusetts Institute of Technology, Purdue University, and Quinnipiac College.

Douglas-developed econometric methods were used to forecast traffic through the year 2000. The traffic estimates for the 18 international IATA regions were the data source. Further considerations of range, traffic, and mileage over land reduced the base to 10 regions. These 10 regions were used as the arena of competition between the HSCT and an advanced subsonic transport reference vehicle. These regions are primarily intercontinental, over water, and long range. Four regions comprise between 85 to 90 percent of the total international traffic (Figure 2). The North Atlantic and North and Mid-Pacific are the major traffic regions. In 1986, the North Atlantic recorded more than twice the revenue passenger miles compared to the North and Mid-Pacific. By the year 2000, equal traffic is expected in these two major sectors. Overall, traffic is predicted to total 446 billion available seat-miles (ASM), with 53 percent being over water routes. These projections are based on individual country economics, trade characteristics, and priorities.

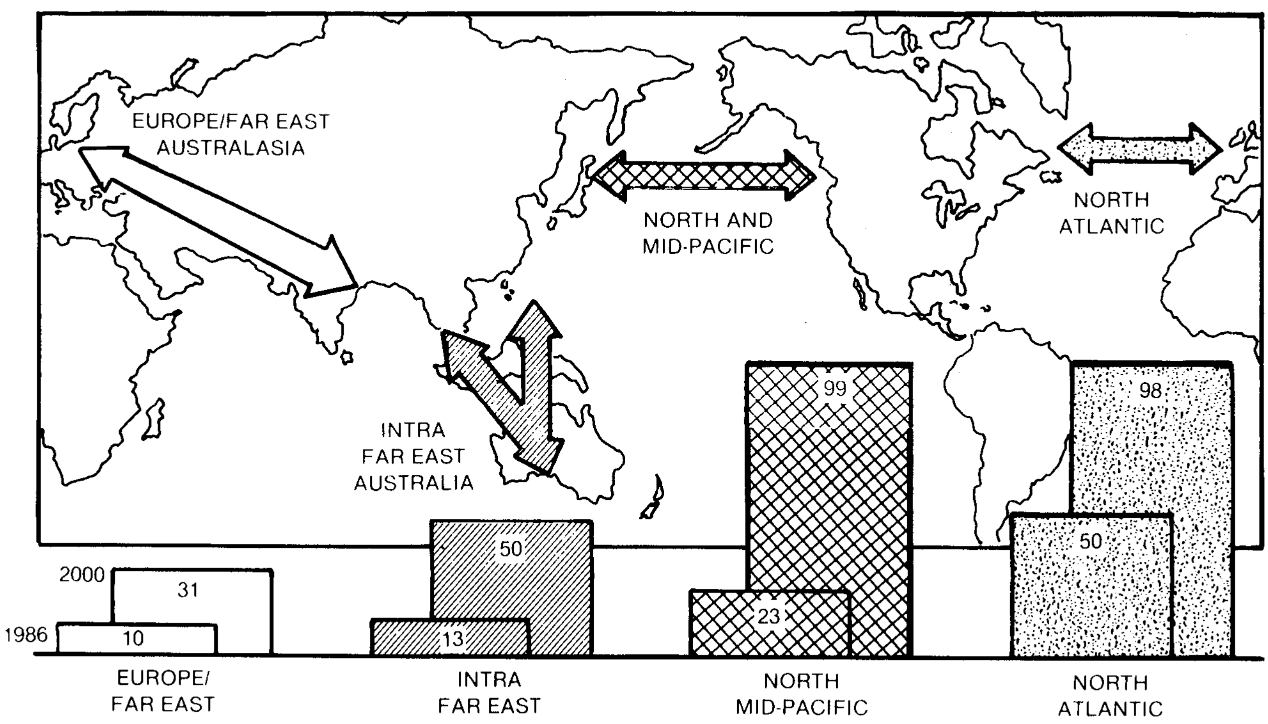


FIGURE 2. INTERNATIONAL PASSENGER TRAFFIC FOR MAJOR REGIONS

For the period of 2000 through 2025, three economic scenarios were considered: (1) uninhibited growth at the rates in the final years of the 1986-2000 time period, (2) continued rapid growth in the Pacific Rim countries with rates moderating in the latter half of the 25-year period, and (3) growth rates decreasing to the levels of the projected rates in the general economies of the regions. Of the three scenarios considered, the second with a growth to 2,386 billion seat-miles is considered most likely (Figure 3). This represents five times the traffic projected for the year 2000. These data represent a first-order market assessment and basis for productivity and utilization analysis; and they do not represent an exhaustive research for HSCT opportunities.

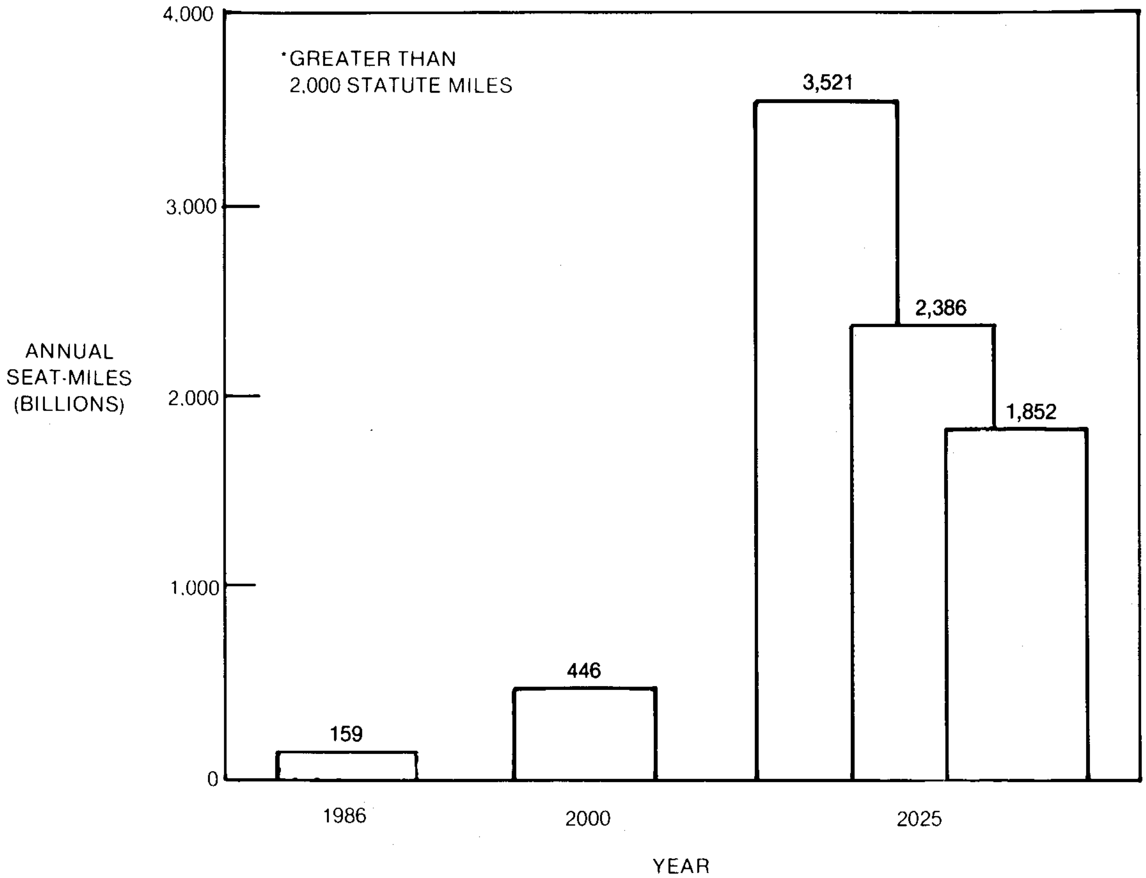


FIGURE 3. PASSENGER TRAFFIC FORECAST

Based on this market analysis and previous Douglas supersonic aircraft studies, a vehicle size of approximately 300 seats is necessary for competitive economics; therefore, all vehicles were sized accordingly. The passenger market is segmented into four fare classes; first class, business, and coach including full fare and discount fare base. First class, business, and approximately half of the full-fare coach market travel primarily for business reasons and the remainder travel for personal or pleasure reasons (Figure 4). It is assumed that the HSCT will be operated based on current airline business practices of fare management and thus accommodate all levels of passenger traffic. Correspondingly, HSCT economic analyses include fare distinction by class of service.

Range requirements will be mandated by the key Pacific markets with an eye to the new long-range subsonic transports now emerging. Ranges vary from slightly less than 4,000 statute miles for the Honolulu-to-Tokyo market, to approximately 5,500 statute miles for the Los Angeles-to-Tokyo market, to nearly 7,000 statute miles for the New York-to-Tokyo market (Figure 5). Los Angeles to Sydney, with 7,500 statute miles, represents the upper nonstop range requirement. This range capability captures 80 percent of all long-range, nonstop traffic, and thus was adopted as a design requirement. In addition, other design objectives were established based on the assumption that for an HSCT to be viable, it must be operable from current airports. This included a maximum takeoff field length of 11,000 feet and maximum takeoff gross weight of 1,000,000 pounds. Approach

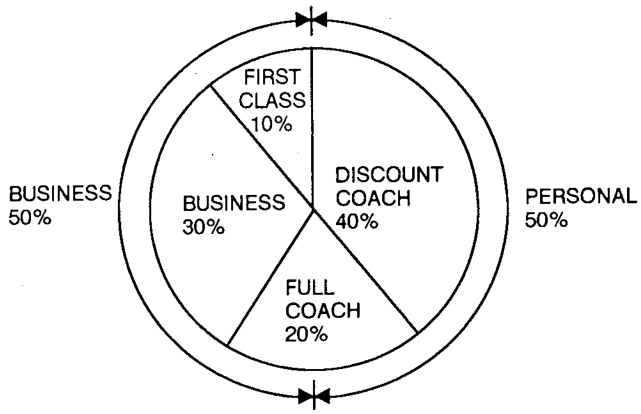


FIGURE 4. PASSENGER DISTRIBUTION

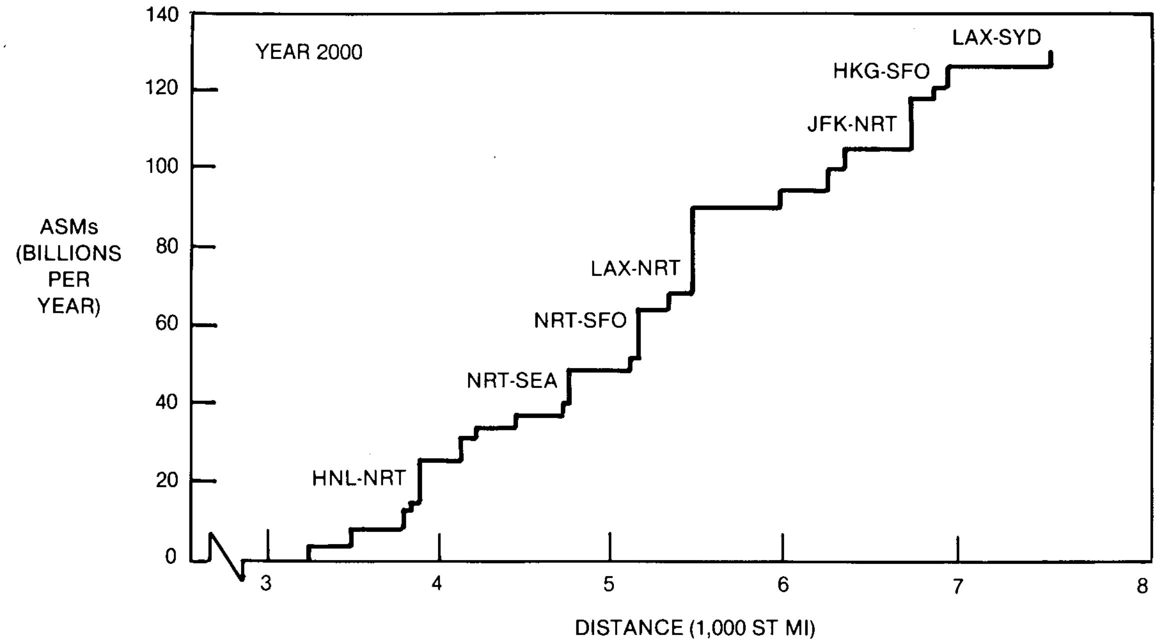


FIGURE 5. TOP PACIFIC REGION MARKETS

speeds of 140 knots will maintain compatibility with ATC. Accelerations not to exceed 1/10 g during climb will assure passenger comfort. Environmental acceptability is a key requirement.

Market stimulation by HSCT flight-time savings is considered to be a significant advantage by airlines. There is positive evidence that the advent of jet travel and the resulting time savings caused accelerated market growth particularly over the long-distance routes. Airlines consulted during this study believe a viable HSCT could cause similar market response but no attempt was made to quantify levels. The favorable affects of HSCT flight-time savings when crossing many time zones will reduce jet lag. Jet lag encompasses the feelings of irritability, mental and physical lethargy, disorientation, and fatigue. Adjustment for the jet lag occurs in about the time that it takes for the sleep-dependent and physical parameters to fall back into phase. The sooner a passenger arrives in the new time zone, the sooner the readjustment begins; a matter of hours is significant. Figure 6 shows the significant reduction to time changes achievable through flight-time reductions. Round trips in one day should not create jet lag problems for those business travelers who take advantage of the short travel times nor for HSCT crews.

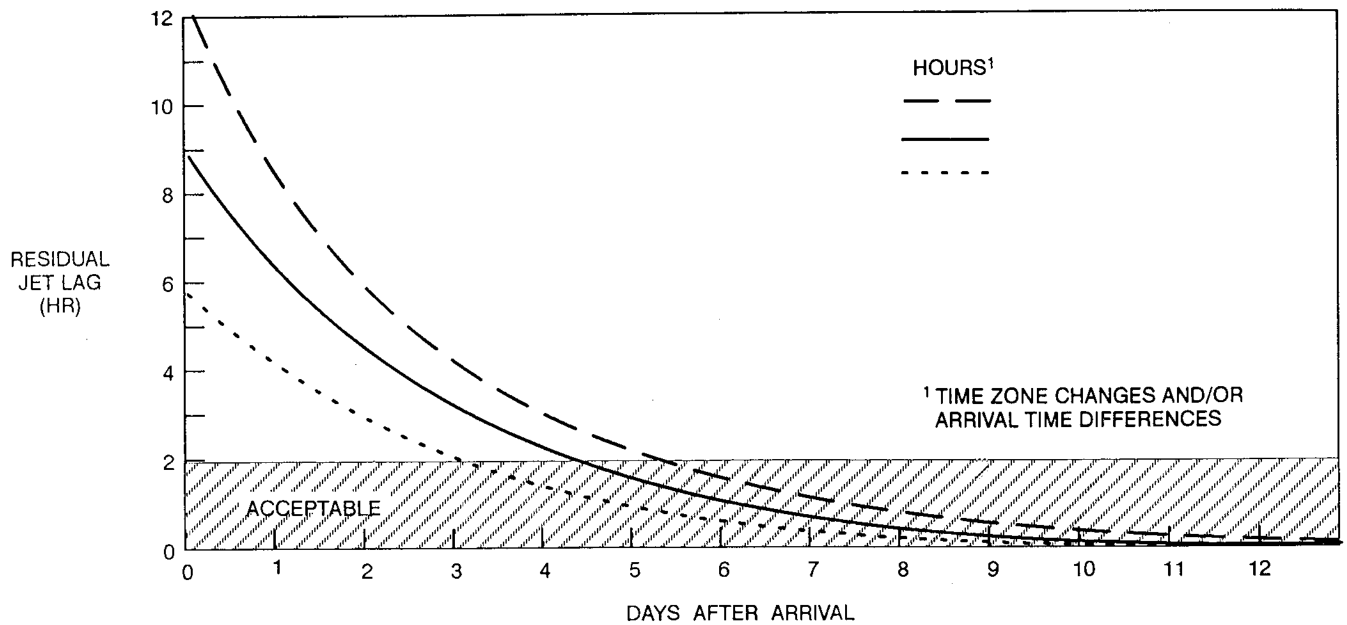


FIGURE 6. READJUSTMENT TO TIME CHANGES

Market research highlighted more than 300 international city-pairs as candidates for HSCT service. A global concept airline routing system consistent with current airline scheduling for large transport aircraft was developed to determine aircraft use considering HSCT speed potential, real-world constraints such as airport curfews, and passenger preferred times of day for travel. From this, aircraft productivity (seat-miles-per-year) was determined based on cruise Mach number (Figure 7) assuming a 2-hour aircraft turnaround time and market applications ranging from 2,000 to 6,500 nautical miles.

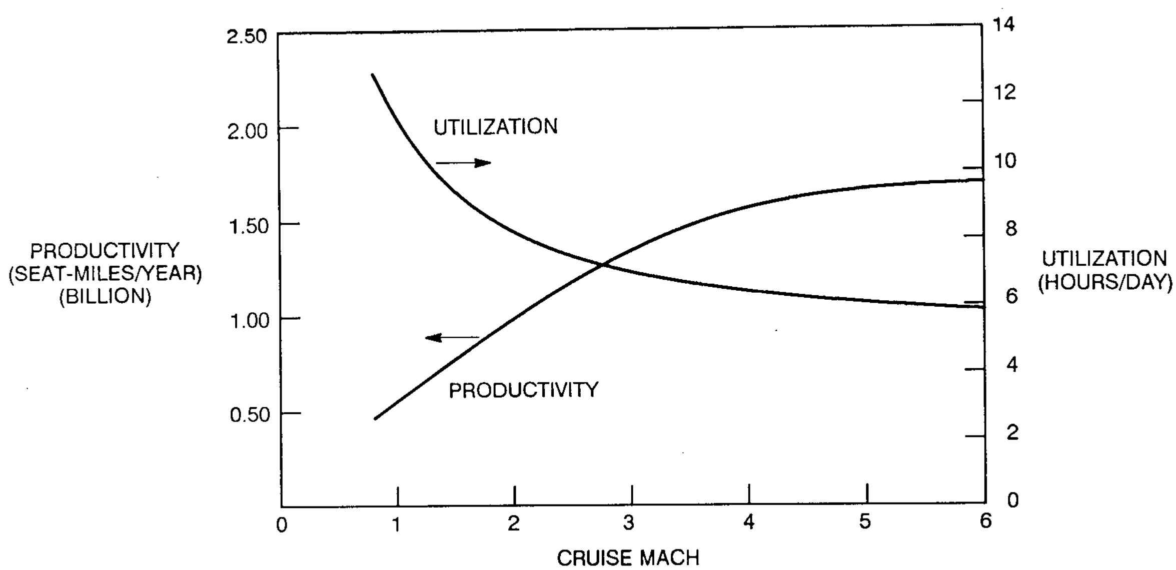


FIGURE 7. AIRCRAFT PRODUCTIVITY AND UTILIZATION

Scheduling results showed the expected increase in productivity as cruise speed increased. In the Mach 4 or 5 range, productivity gains begin to diminish; and above Mach 6, very little additional productivity is achievable. Thus, Mach 5 to Mach 6 represents the commercial upper limit within the current air transportation system of nonstop, point-to-point service. Figure 7 includes the resulting aircraft daily utilization as a function of cruise Mach number.

Passenger value of time, fare premiums, and blocktime differences between the HSCT and competing subsonic aircraft affect market share. The underlying assumption is that a traveler will be an HSCT passenger if the monetary value of the time savings exceeds the fare premium. The passenger market is segmented into four different fare classes ranging from first-class travelers with a relatively high value of time to a highly price-sensitive aft cabin or discount coach market.

Figure 8 shows the potential traffic assuming no supersonic cruise over land will be allowed and the significant effect of fare premium on market capture. The data reflect subsonic cruise range capability.

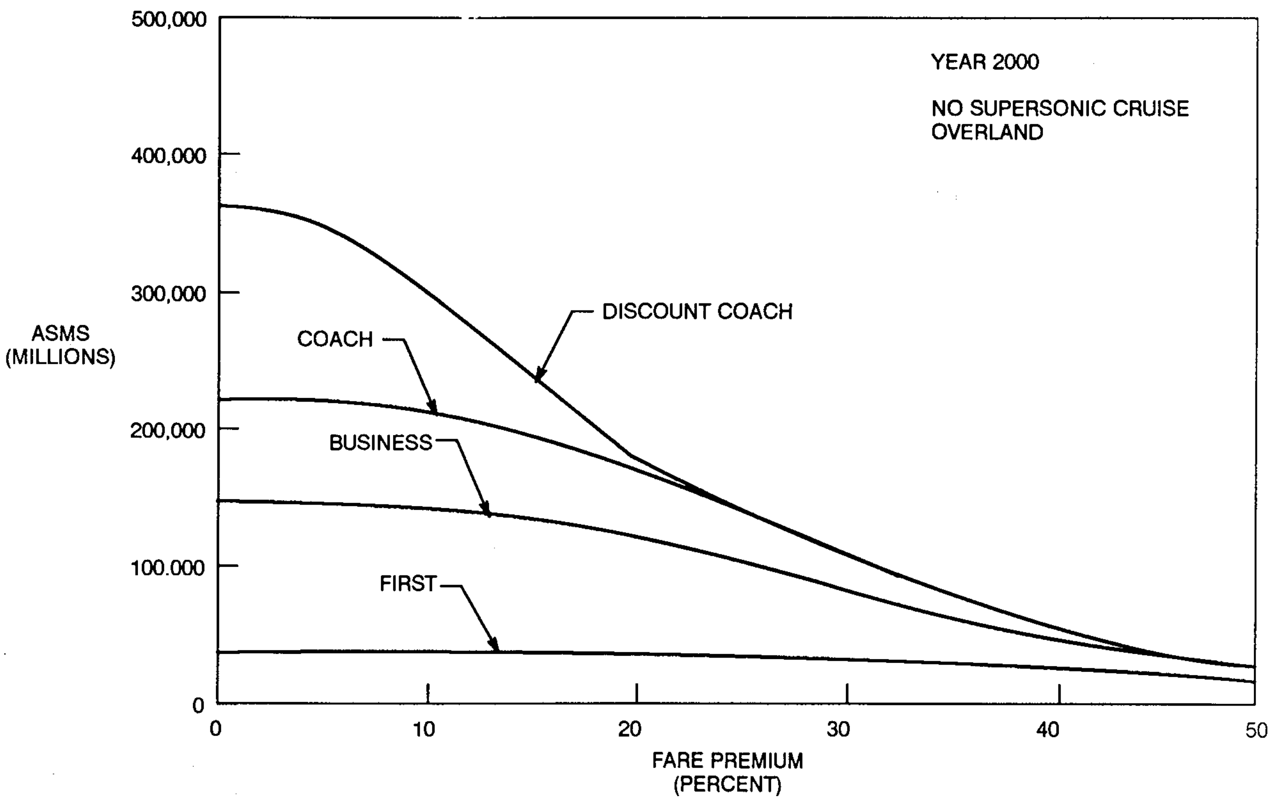


FIGURE 8. EFFECT OF FARE PREMIUM ON MARKET CAPTURE

World passenger jet aircraft requirements (excluding the USSR) are expected to total about 10,000 aircraft in 2000 with about 1,800 aircraft in the long-range (greater than 3,500-nautical-mile range) class. Approximately one-half of this long-range market is potential for the HSCT system. The HSCT with no fare premium may take the place of a maximum of 900 aircraft and since the HSCT is some 2.5 to 3 times as productive as a subsonic aircraft of the same size; 300 to 450 HSCT could do the work of 900 subsonic aircraft. If high-speed cruise over land is prohibited, then requirements will be reduced by as much as 20 percent. If premium fares are required, then the fleet sizes are further reduced. The HSCT fleet requirements in the year 2000 are shown in Figure 9 for the eight international (IATA) region system considered appropriate in view of the supersonic cruise over land limitation. The share of the long-range market depends on fare premium and, ultimately, on the operating costs.

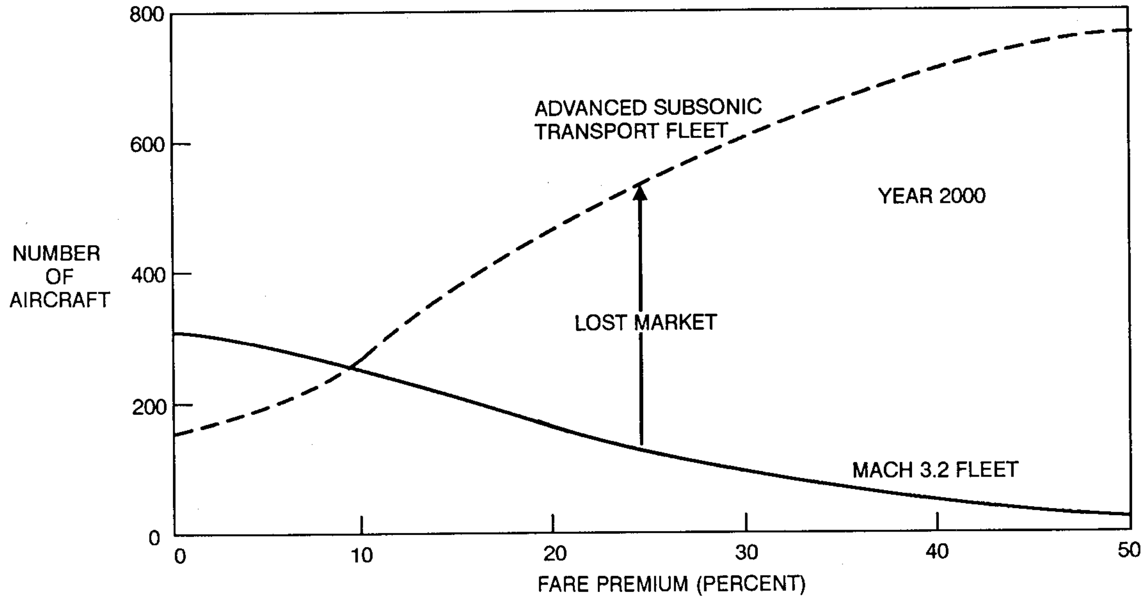


FIGURE 9. HSCT FLEET REQUIREMENTS

VEHICLE CONCEPTS

The initial study efforts consisted of a broad screening analysis of the Mach 2 to 25 range. The development of the HSCT benefitted from related work. This includes the supersonic transport work of the 1960s; the AST activity of the 1970s, follow-on research by NASA, the Concorde, and the NASP. HSCT prime design objectives are: accommodation of 300 passengers and a design range of 6,500 nautical miles (7,500 statute miles). In addition to passenger baggage, 500 cubic feet of volume is provided for 5,000 pounds of cargo. As a U.S. civil aircraft, the HSCT will be certified and operated per FAA code of Federal Regulations. The design and certification will conform to Part 25, and it will be operated under Part 91 and Part 121.

During the early study phases, a large number of candidate engines Mach number/fuel combinations were evaluated. This included both military and commercial concepts and ranged from preliminary designs developed for the high-speed propulsion (HSPA) studies for the Air Force, to commercial engines specifically tailored to the Douglas high-speed civil transport configurations. Engine data have been supplied by Aerojet TechSystems, General Electric Aircraft Engines, and Pratt & Whitney. All studies assumed an aircraft certification date of 2000/2010, with a corresponding technology availability date (TAD) of 1995/2000.

For high-speed applications, the choice of fuel is of broadened importance: the fuel energy content influences the size and weight of the airplane; the heat sink capability and thermal stability limits of the fuel influence the Mach number. Some of today's fuel supply has been shown to have thermal stability limits above that of Jet A (today's commercial standard fuel). This indicates that kerosene-based fuels can be produced with enhanced thermal capability. The cost of the fuel becomes a more predominant factor in the operating economics.

HSCT fuel system design is similar to that of the conventional subsonic airplane for cruise speeds up to Mach 2.0 or 2.5. At higher cruise speeds, the requirements for an enhanced thermal stability kerosene fuel or for LNG fuel may require extensive changes in the fuel system configuration. Aircraft gas turbine engines have been designed and operated routinely with kerosene fuels in both commercial and military airplane service. They also have accumulated millions of hours of operation on natural gas fuel in dual fuel marine and industrial applications. Commercial jet engines experience fuel temperatures on the order of 325°F. The SR-71, using JP-7 fuel, is able to accommodate fuel temperatures as high as 600°F. Figure 10 presents a matrix of vehicles and fuels considered.

An advanced subsonic transport incorporating technologies expected in the year 2000 and using conventional Jet A fuel was defined to provide an economics baseline. Mach 2.2 and Mach 4 vehicles used a kerosene-type fuel with higher thermal capability. In addition, the Mach 4 studies also included endothermic and cryogenic fuels. Endothermic fuels were eliminated because of price and availability. Liquid methane offers a 16-percent higher energy per pound; however, it has an energy density only 60 percent of that of kerosene-type fuels. Liquid hydrogen (LH_2) also offers an increase of energy (180 percent) at a still further reduced energy density (25 percent). Initial concept evaluations included comparisons of aircraft worth (to the operator) and flyaway price. The hydrogen-fueled concepts fell short in aircraft worth because of high LH_2 fuel cost and thus were dropped from further consideration.

The following Mach numbers were selected for more detailed study with the rationale for their selection as follows:

- Mach 3.2
  - Higher productivity than Mach 2.2
  - Upper limit of kerosene-based fuel
  - Aggressive technologies
- Mach 5.0
  - Highest productivity
  - Application of methane fuel
  - More aggressive technologies including NASP

Commercial airplane operations beginning in the 2000/2010 time period focus these studies to kerosene-based jet fuels and LNG. It is generally agreed that the thermal stability of Jet A is a limiting factor in high Mach number applications. Based on inputs from refiners and engine manufacturers, JP-7 was chosen by Douglas as the reference fuel for the Mach 3.2 studies. The properties of JP-7 that are desirable from the standpoint of commercial application are related to thermal stability; however, some of the properties of JP-7 may not be required. The term *thermally stable jet fuel* (TSJF) was adopted for this study.

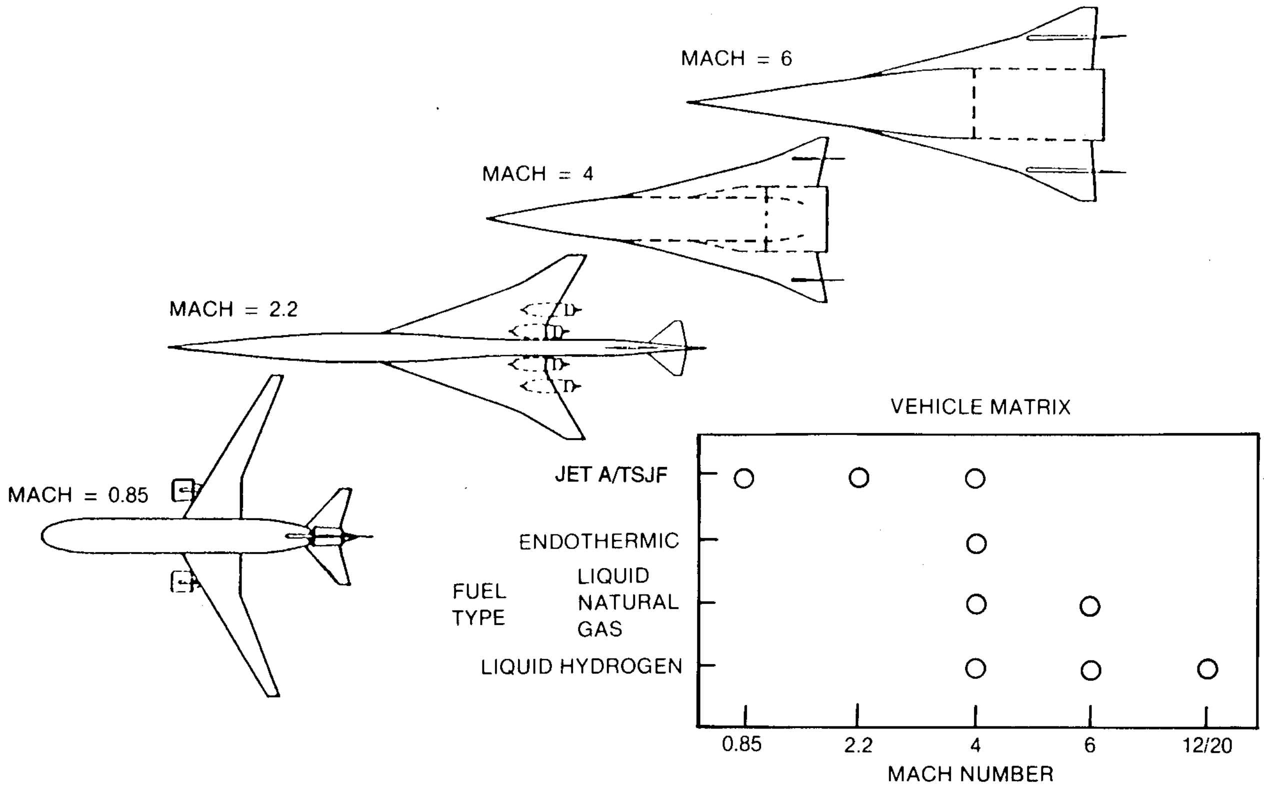


FIGURE 10. HSCT STUDY CONCEPTS

One important parameter for preliminary screening was engine overall cruise efficiency. Overall efficiency is approximately equal to the product of the specific impulse times the flight velocity divided by the fuel heating value. It is a measure of fuel energy conversion to jet kinetic energy and is the product of the thermal efficiency and propulsive efficiency. Specific impulse, I_{SP} (I_{SP} = 3,600/SFC) is used in lieu of specific fuel consumption, SFC. Depending upon the design mission, fuel consumption during climb can amount to 25 percent or more of the total fuel weight at takeoff. In the event that sonic boom restrictions preclude supersonic flight over land, the aircraft may have to fly up to 40 percent of its design range at subsonic speeds. Thus the cycles with the best supersonic cruise overall efficiencies, generally turbojets, will not necessarily be the optimum for the vehicle. Engine cycle selection was made on the basis of vehicle takeoff gross weight and FAR Part 36, Stage 3 takeoff noise requirements. The resulting engine efficiency levels are shown in Figure 11 compared to a potential upper level. This evolved from studies of engine component performance and represents a variety of engines and fuels. Engines developed for this study offer 20- to 25-percent improvement when compared to the Concorde; however, exhibit efficiency levels significantly below the potential upper bound. It is expected that more focused efforts will result in higher efficiency levels and corresponding improvement to vehicle performance.

Advanced Subsonic Transport

Throughout the study, an advanced subsonic transport, incorporating projected technology improvements for the year 2000, has been used for economic comparisons. The vehicle features an advanced wing, very-high-bypass ducted fan engines burning conventional Jet A fuel and advanced systems. The configuration is shown in Figure 12. The Mach 0.85 concept was based on Douglas Aircraft Company's development work for the MD-11 and employs a shortened fuselage for consistency with a 300-passenger interior and an all new, high-aspect-ratio supercritical wing with an aspect ratio of 11.41, and a span of 174.9 feet. Riblets were applied to the wing, tail, fuselage, and nacelles. A hybrid laminar flow control system was included together with a wet tail for cg control. The trimmed lift-to-drag ratio for the concept was 21.5.

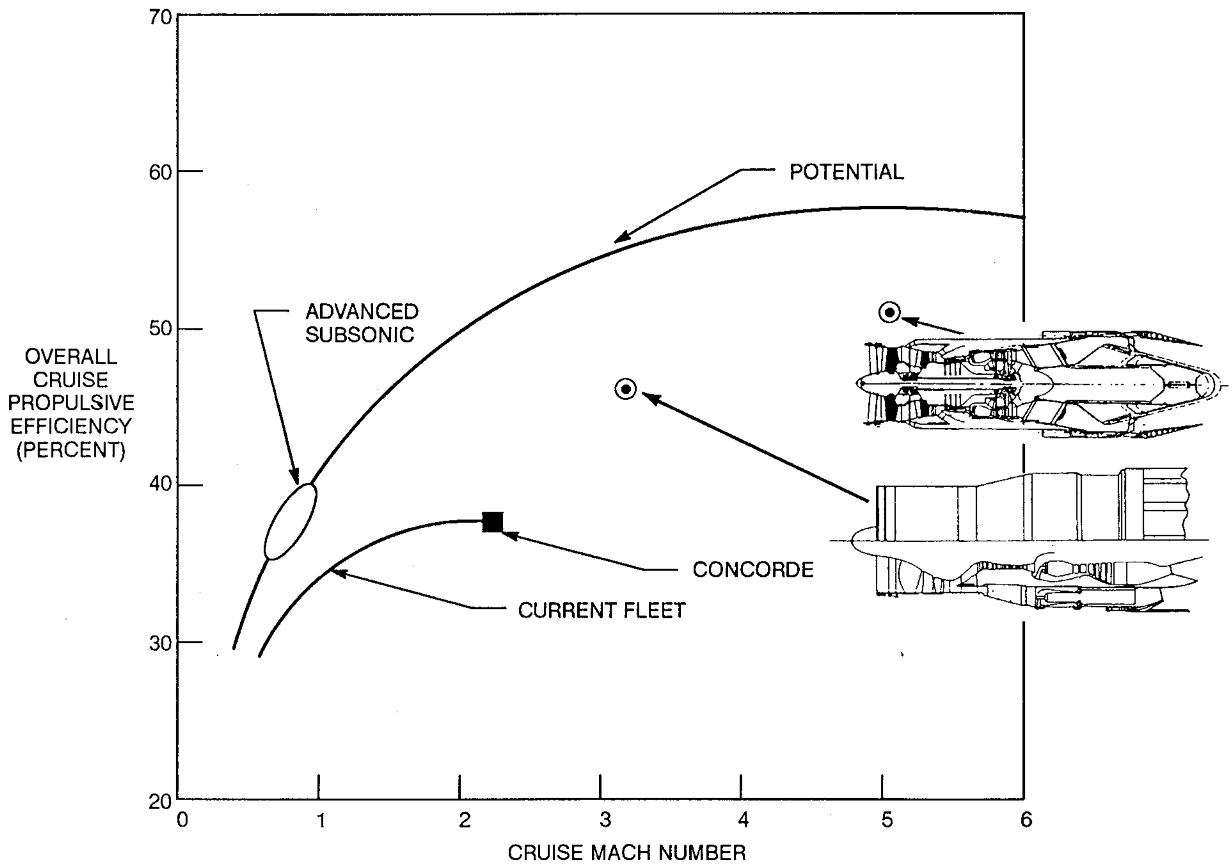


FIGURE 11. ENGINE EFFICIENCY

The Mach 0.85 configuration incorporated application of newer materials and fabrication techniques. SCS-8/Al 6061 aluminum metal matrix being the most efficient material and having both a high specific moduli and specific compressive yield strength was used for the structure. To further reduce the weight, honeycomb construction was used for the load-carrying skins instead of traditional skin-stringer design. It was estimated that honeycomb construction would result in an approximate 15-percent weight reduction.

The P&W Advanced Ducted Prop (ADP) engine has been selected as a representative advanced subsonic engine for long-range aircraft. The ADP is a two-spool, geared high-bypass, high-pressure ratio, ducted prop engine with separate core (primary) and prop (duct or bypass) exhaust streams. One of its significant features is a variable pitch ducted prop that provides good operability as well as reverse thrust. The cycle and component design parameters for this engine are:

• Overall pressure ratio	36
• Fan pressure ratio	1.3
• Bypass ratio	15
• Maximum combustor exit temperature	2,650°F

Mach 3.2. The Mach 3.2 baseline concept, D3.2-3A (Figure 13), was based on the design work conducted for the 1979 AST (Reference 1), under joint NASA/McDonnell Douglas funding. The configuration features a double-sweep arrow planform wing, conical-taper fuselage, aft vertical and horizontal empennage, four P&W duct-burning turbofan engines, TSJF, and a tricycle landing gear.

The fuselage was designed to accommodate a nominal seating arrangement of three classes: 10-, 30-, and 60-percent for first, business, and coach classes, respectively. The concept developed was unaffected by constraints for sonic boom optimization. Supersonic drag necessitates use of a varying cabin cross section. The fuselage incorporates single-lobe shaped cross sections; the maximum section is determined by a twin aisle with

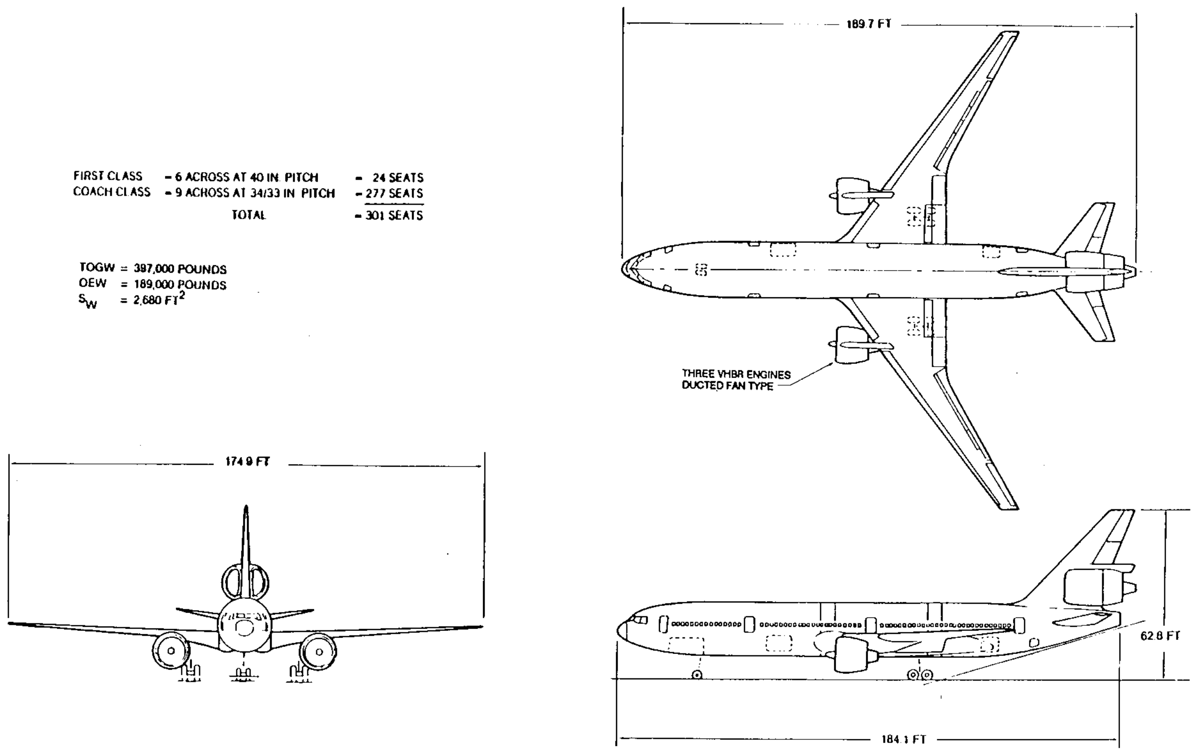
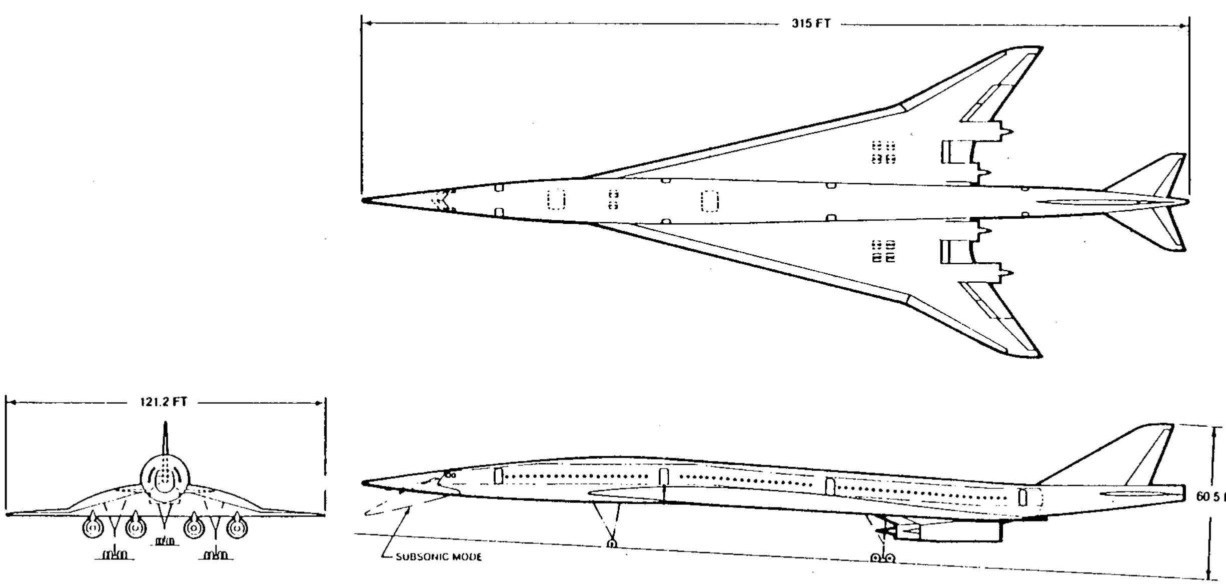


FIGURE 12. ADVANCED SUBSONIC TRANSPORT



TOGW = 769,000 POUNDS
OEW = 231,335 POUNDS
S_W = 9,500 FT^2

PAYLOAD

FIRST CLASS	= 10 PERCENT	= 4 ACROSS AT 42 IN. PITCH	= 30 SEATS
BUSINESS CLASS	= 30 PERCENT	= 4 6 ACROSS AT 38 IN. PITCH	= 90 SEATS
COACH CLASS	= 60 PERCENT	= 4 5 ACROSS AT 32 IN. PITCH	= 180 SEATS
TOTAL	= 100 PERCENT		= 300 SEATS

FIGURE 13. MACH 3.2 BASELINE CONFIGURATION (D3.2-3A)

seven-across coach seats, six-across first/business-class seats, and the minimum section is determined by a single aisle, five-across coach seating arrangement or four-across business-class seats. All seat sizes are consistent with those on MD-80 and MD-11 aircraft. The baseline interior arrangement provides service for 300 passengers based on a maximum flight duration of 5 hours. Each class has its own galley, lavatories, coatrooms, and cabin attendant stations. Four cabin doors per side are evenly distributed for rapid evacuation. Cabin windows are incorporated.

The basic arrow-wing AST planform was modified with increased leading- and trailing-edge sweep to improve supersonic performance at Mach 3.2 cruise. The wing design had a planform reference area of 9,500 square feet, an aspect ratio of 1.55, an inboard leading-edge sweep of 76 degrees and an outer panel leading edge sweep of 62 degrees. The wing was optimized for a maximum wing-body trimmed lift-to-drag ratio. The fuselage area distribution and camber were optimized for minimum wave drag at cruise conditions. The high-lift system consisted of plain, trailing-edge flaps and full-span, simple-drooped leading-edge flaps. Laminar-flow control (LFC) inboard of the wing planform break was limited by the fuel tank boundaries. Outboard of the planform break, LFC extended to the flap-hinge line.

Longitudinal control and trim capability were provided by a totally movable horizontal surface with a geared elevator. Ailerons and spoiler panels provided lateral control; directional control was provided by a rudder.

A major environmental issue lies in the sonic boom resulting from supersonic cruise flight. A derivative of the baseline configuration was developed to increase performance efficiency during subsonic flight over land. This configuration, D3.2-4B, incorporates a wing planform modified to increase the span and reduce the leading-edge sweep of the outer wing panels (Figure 14). The maximum trimmed cruise lift-to-drag ratio of the Mach 3.2 configurations are shown in Figure 15 for the subsonic and supersonic flight profiles over land. The difference in the subsonic lift-to-drag ratios (shown for the -3A) was due to flight at lower altitudes.

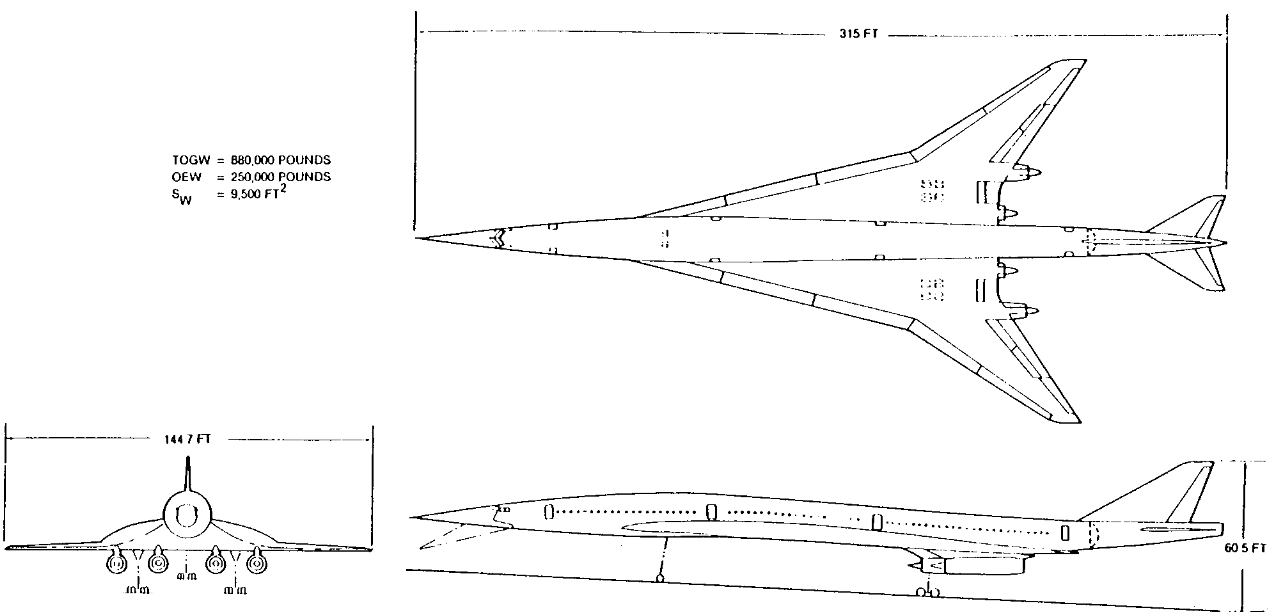


FIGURE 14. MACH 3.2 INCREASED SPAN CONFIGURATION (D3.2-4B)

The Mach 3.2 baseline engine is the P&W variable stream control engine (VSCE) duct-burning turbofan using TSJF. The VSCE (Figure 16) is an advanced, moderate-bypass-ratio, nonmixed-flow turbofan with duct burner augmentation and a coannular nozzle with inverted velocity profile for jet noise reduction. P&W provided a preliminary assessment of takeoff noise reduction which identified the VSCE and the turbine bypass

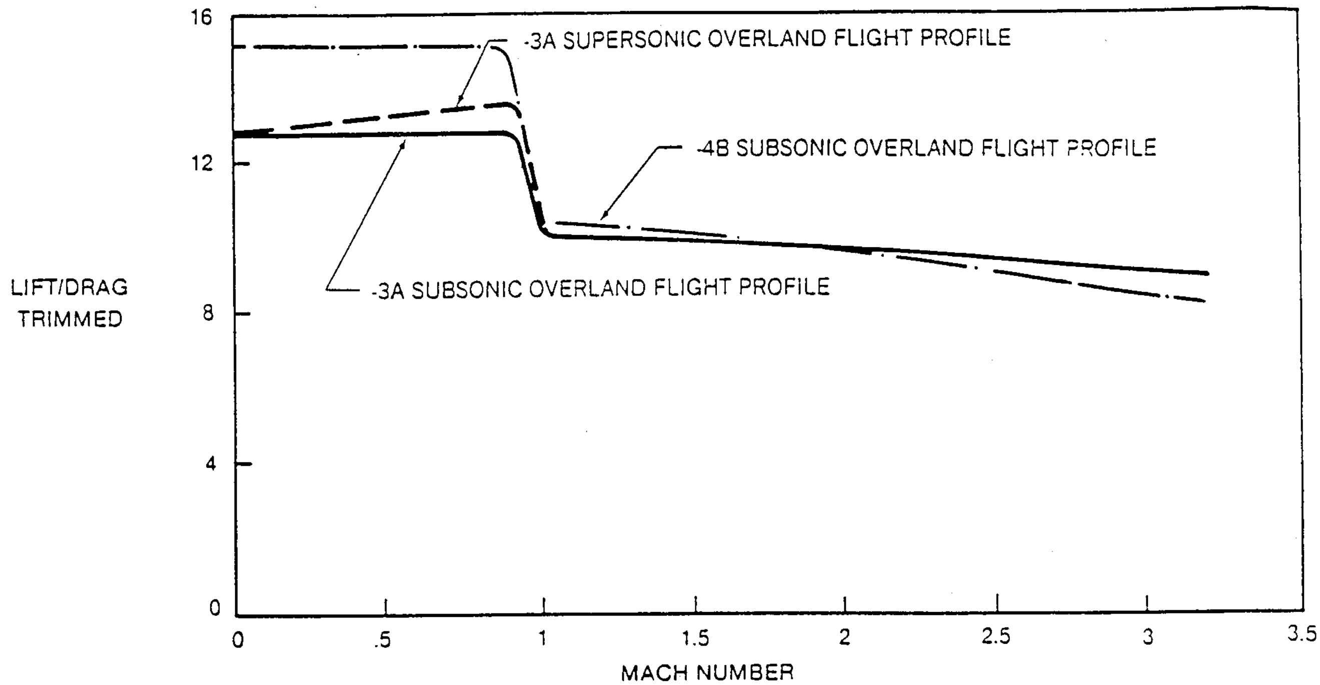


FIGURE 15. MACH 3.2 LIFT/DRAG

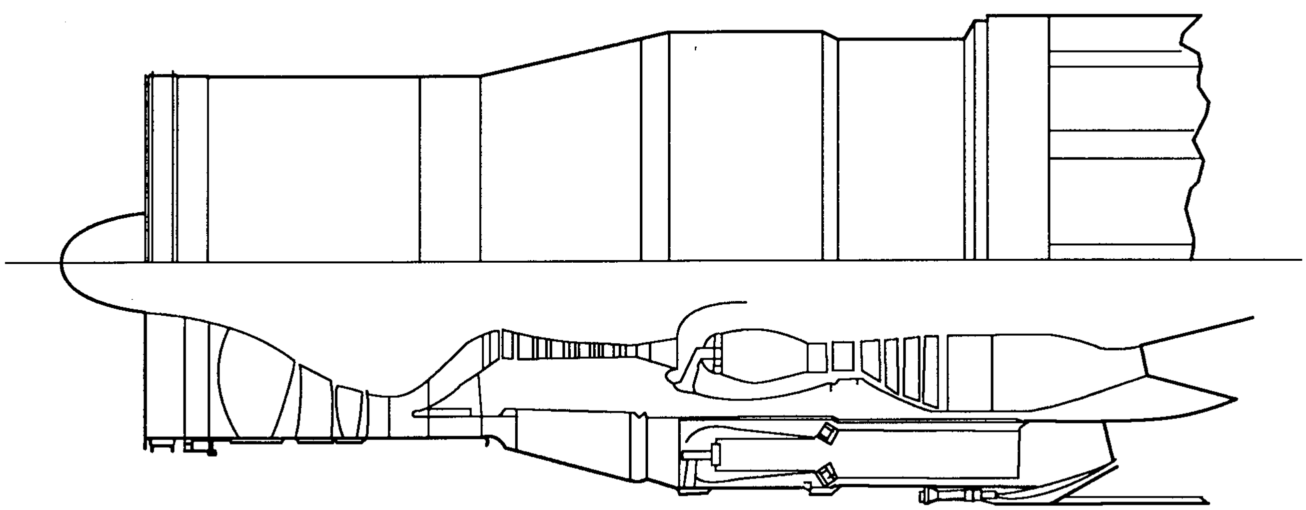


FIGURE 16. P&W MACH 3.2 VARIABLE STREAM CONTROL ENGINE

engine as having the greatest potential for satisfying FAR Part 36, Stage 3 requirements, with the VSCE having the advantage due to its inverted velocity profile (IVP). A variable area suppressor allowed optimization of jet noise at the sideline condition. In addition, an acoustically treated ejector nozzle was employed. A distinctive operating feature is the independent control of core and fan (duct) stream temperature and exit velocity for cycle matching with the following advantages:

- Meets thrust requirements over the entire flight spectrum
- Provides low-core exhaust velocity for noise benefits
- Minimizes cruise fuel consumption

At takeoff, the main burner is throttled to reduce jet noise. The duct burner is operated to provide an inverted velocity profile. The thrust can be cut back for noise abatement after takeoff while still maintaining the inverted velocity profile. During subsonic cruise, the VSCE operates as a moderate bypass turbofan engine with no duct augmentation. Variable geometry components are matched to reduce inlet spillage and bypass losses. During supersonic cruise, bypass ratio and duct augmentation are reduced to maximize propulsive efficiency. Key parameters are:

• Overall pressure ratio	14.3
• Fan pressure ratio	3.67
• Design bypass ratio	1.30
• Maximum compressor discharge temperature	1,860°R
• Maximum turbine inlet temperature	3,960°R

A variable geometry bicone inlet with wing-leading edge precompression was utilized based on the results of Douglas supersonic transport studies conducted in the late 1970s. The nozzle concept is based on studies performed by Douglas and incorporates a combination of suppression techniques to meet FAR 36, Stage 3. Inlet bleed air will be used for nozzle/engine cooling and then injected into the engine exhaust to aid in noise reduction. The engines are individually mounted in nacelles under the wing. Fuel will be supplied in shrouded lines to the engine by routing it through the nacelle pylon. Pressure relief and drainage is provided. Maintenance can be performed using ground access stands and conventional equipment.

The alternate Mach 3.2 engine is the GE variable cycle engine (VCE) using TSJF. The VCE is twin spool, with double bypass variable geometry to optimize fan/compressor/turbine match over the flight spectrum to maximize subsonic and supersonic cruise performance. The engine is not augmented. The VCE incorporates an axisymmetric nozzle with translating nozzle shroud and inner plug to vary the nozzle throat area. During takeoff, the bypass flow is diverted through struts, forcing the flow along the inner plug to achieve an IVP for jet noise reduction. Key parameters are:

• Overall pressure ratio	22
• Fan pressure ratio	4.8
• Bypass ratio	0.5
• Maximum rotor inlet temperature	4,000°F

The maximum temperatures the Mach 3.2 aircraft will experience range from 400°F to 680°F (Figure 17). The maximum temperature on the fuselage nose is 680°F; the leading edge temperatures are 625°F for the wing and 530°F for the empennage. Fuselage lower surface temperatures range from 525°F to 590°F, and the upper fuselage surface temperatures range from 400°F to 460°F.

Thermal management included both external and internal heat sources and dissipation requirements to maintain energy balance. Fuel was used as the primary heat sink for absorbing energy loads. Except for the engine inlet and nozzle, the aerodynamic heating of the aircraft was regulated by passive (i.e., insulation) thermal protection systems (TPS). Modularized Multilayer Insulation (MMLI), consisting of layered nickel reflector foils was employed. The wing tank insulation limited the fuel tank temperature rise due to aerodynamic heating to a maximum limit of 200°F for the TSJF. The cabin air temperature was maintained at 70°F.

Candidate structural materials consist of aluminum, titanium, polymetric composites (PC), aluminum metal matrix composites (Al MMC), and Ti metal matrix composites (Ti MMC). Up to 480°F, the Al MMC (SCS-8/RSR Al) has the best specific moduli value and the specific yield strength is relatively high. The Ti MMCs are more suitable structural materials for higher speeds. The polymer composite material, Celion 6K/PMR-15, and RSR Al are possible candidates for the Mach 3.2 concept; however, they do not offer the weight savings potential of Al MMC. Titanium materials having properties approximately 50 percent lower than Al MMC would result in a less efficient and heavier structure. Buckling, crippling, stiffness, tension, and other failure modes play important roles in the selection of materials for the primary structure of an aircraft with buckling and crippling accounting for approximately 75 percent of the primary structural weight. SCS-8/RSR Al is the most efficient material considering buckling-crippling and thus was used for the structural material of the Mach 3.2 concept.

Various flight conditions, maximum loads, maximum temperatures, and other pertinent conditions (flutter and landing) were examined to verify structural integrity of the components. A finite element model (FEM) of the Mach 3.2 concept was developed representing skins, spars, ribs, frames, and longerons. Fuel tank structure, landing-gear elements, nose/leading-edge structure, and LFC elements were included in the evaluation. The FEM included the temperatures, materials, and loading conditions and was utilized to check stresses and deflections to ensure structural integrity. Minimum gage materials were used as much as possible. The aircraft,

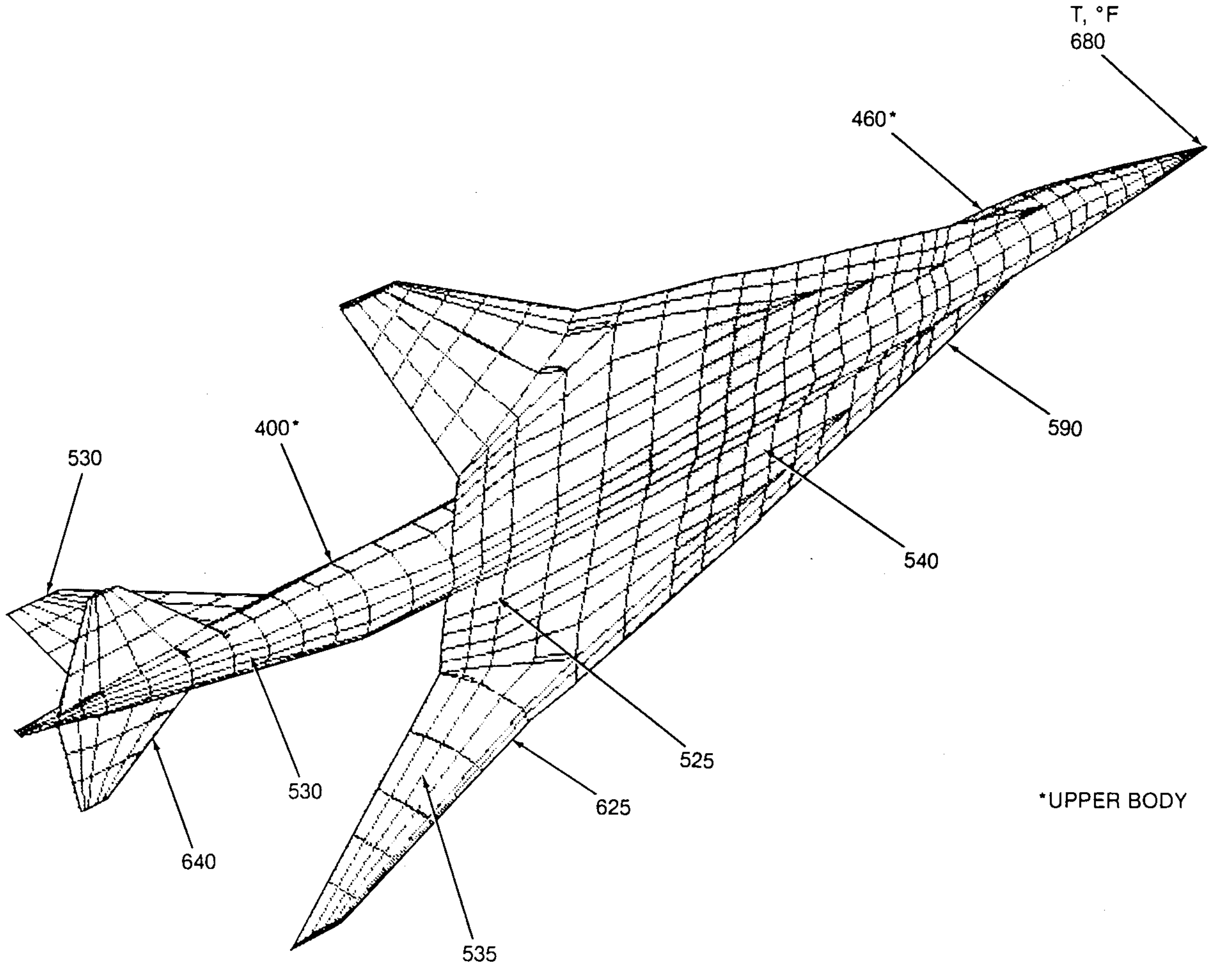


FIGURE 17. MACH 3.2 MAXIMUM TEMPERATURES

under limit-load critical design case, was examined to ensure that there are no structural deformations or deflections that would inhibit movement of the control surfaces, such as the ailerons or flaps.

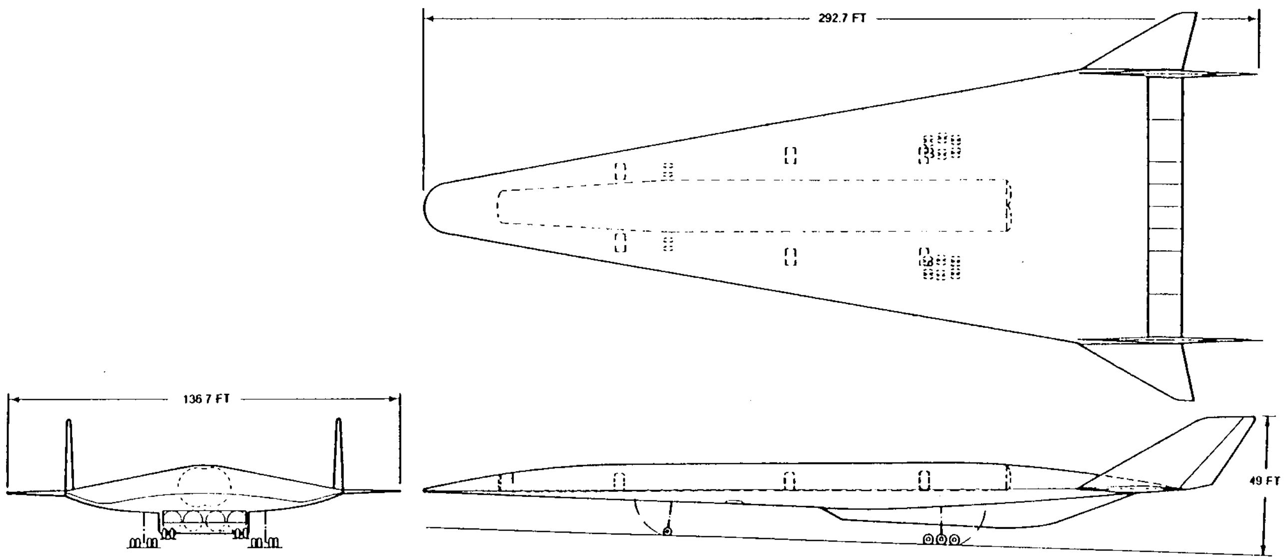
Various structural concepts for the major structural components were examined including conventional skin-stringer design, super-plastically formed, diffusion bonded (SPF/DB) structure, and honeycomb construction. The optimization analysis included strength, stability, crippling, and thermal stresses. As a result, SCS-8/RSR Al MMC honeycomb construction was selected for the load-carrying members. This resulted in a structural weight reduction of 35 percent relative to mid-1970s technology studies of high-speed commercial aircraft. The structures weights for the Mach 3.2 concept, including the wing, fuselage, and tail sections, were derived from the structural optimization analysis based on commercial aircraft design criteria and standards.

Aircraft systems weights (excluding the TPS) were based on weight data from the Concorde and past NASA/McDonnell Douglas high-speed commercial aircraft studies. System weights reflect assumed improvements due to lighter weight materials and innovative design. Advanced systems such as an all-electric vapor-cycle cabin air conditioning and pressurization system, a fly-by-light flight guidance and control system, an all-electric secondary power system, and an all-electric anti-ice system are incorporated. The auxiliary power unit system has been deleted with reliance on airport ground support utilities. The fuel system weight reflects integral fuel tanks. The LFC system weights include pumps, motors, ducting, controls, and the engine pneumatic bleed system. In addition, an advanced technology glass cockpit (two-person crew) is assumed which includes flat panel displays and multiplexed digital data busses. The Mach 3.2 engine weight is based on data received from P&W.

The operator items weight represents passenger and galley service to accommodate a three-class, 300-passenger cabin. The payload weight is derived as follows:

- 300 passengers at 165 pounds each = 49,500 lb
- 40 pounds of baggage per passenger = 12,000 lb
- Mission payload weight = 61,500 lb
- Cargo at 10 pounds per cubic foot = 5,000 lb
- Maximum space-limited payload weight = 66,500 lb

Mach 5.0. The Mach 5.0 concept, (Figure 18) features a highly swept delta planform with a buried internal passenger cabin. The vehicle slenderness factor, Tau ($\tau = \mathrm{Vol}/S_{projected}^{3/2}$) is 0.069. The fully blended wing-body had a reference area of 17,000 square feet and an aspect ratio of 1.1. Inboard of the planform break, the leading-edge sweep was 80 degrees and outboard the sweep was 60 degrees. Twin vertical tails are located outboard of the horizontal tip pitch/roll control surfaces. The single propulsion pod contains four GE variable cycle hypersonic jet (VCHJ) engines. The propulsion system is highly integrated with the inlet and forebody and the nozzle with the aft body. The landing gear has twin nose struts with dual wheels, and the main gear has two struts with 12 wheels each. Liquid methane fuel tanks are arranged symmetrically around the center of gravity outboard of the pressurized cabin. The primary structure, cabin, and fuel tanks are structurally independent with the pressure cabin suspended from longitudinal trusses.



TOGW = 1,213,000 POUNDS
OEW = 473,805 POUNDS
S_W = 17,000 FT^2

PAYLOAD

FIRST CLASS	= 10 PERCENT	= 4 ACROSS AT 42 IN PITCH	= 30 SEATS
BUSINESS CLASS	= 30 PERCENT	= 6 ACROSS AT 38 IN PITCH	= 90 SEATS
COACH CLASS	= 60 PERCENT	= 8 ACROSS AT 32 IN PITCH	= 180 SEATS
TOTAL	= 100 PERCENT		= 300 SEATS

FIGURE 18. MACH 5.0 CONFIGURATION

The fuselage was designed to accommodate a nominal seating arrangement of three classes: 10, 30, and 60 percent for first, business, and coach classes, respectively. The cabin cross section is a double-lobe type providing for twin aisles and eight-across coach seats, thereby minimizing frontal area and volume. Seat widths are similar to MD-80/MD-11 size (i.e., 42-inch double-seats for coach class). The baseline interior arrangement provides service for 300 passengers based on a maximum flight duration of 3 hours. Each class section has its own lavatories, galley, coatroom, and cabin attendant stations. Three cabin doors per side lead to vertical entry/exit chutes. No cabin windows are provided.

The Mach 5.0 concept was based on previous NASA and industry studies (References 2 and 3) together with detailed configuration integration through application of computational fluid dynamics (CFD) and advanced graphics-based analysis. The blended-body, integrated engine/airframe concept was developed to enhance both aerodynamic and propulsion performance. Laminar flow control was not included. The spatular nose design, developed through CFD study, provided a blunted lift distribution which contributed to sonic boom reduction (Reference 4).

The high-lift system consisted of plain trailing-edge flaps; there were no leading-edge devices. Longitudinal control and trim capabilities were achieved through elevons and movable tip controls. A nozzle flap was used to enhance trim capability. Elevons and movable tip controls were used antisymmetrically to provide lateral control. Directional control was provided by rudders on the two vertical tails. A fuel management system was used to aid longitudinal trimming.

The maximum trimmed lift-to-drag ratios for both overland flight profiles are shown in Figure 19. The difference in the subsonic lift-to-drag ratios was due to flight at lower altitudes.

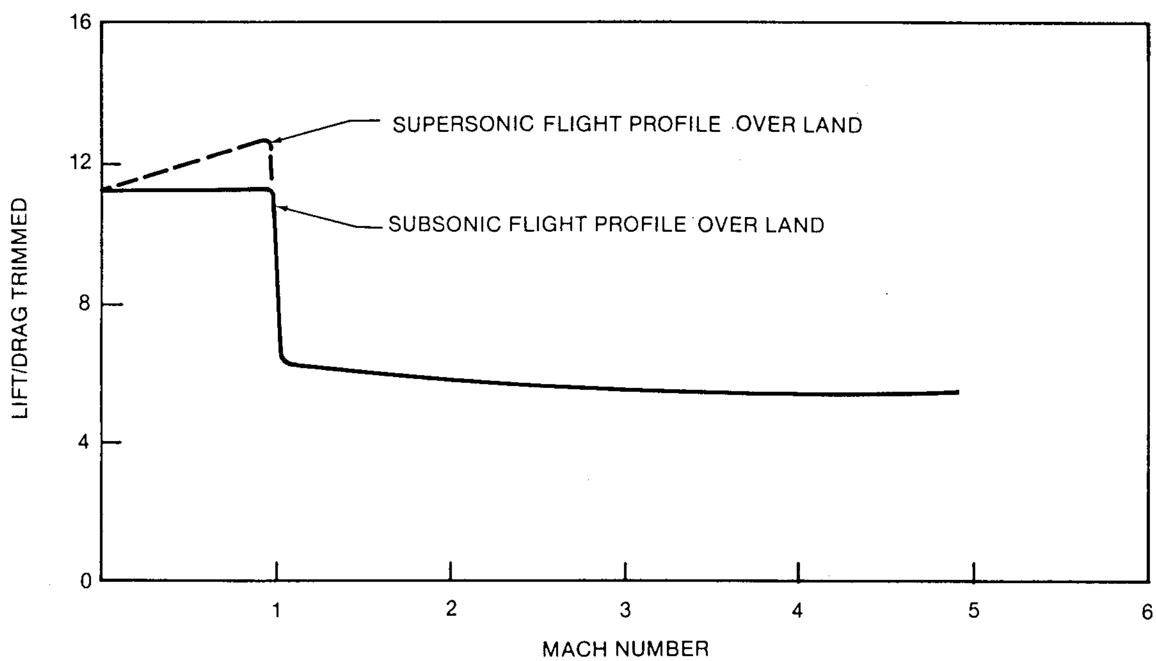
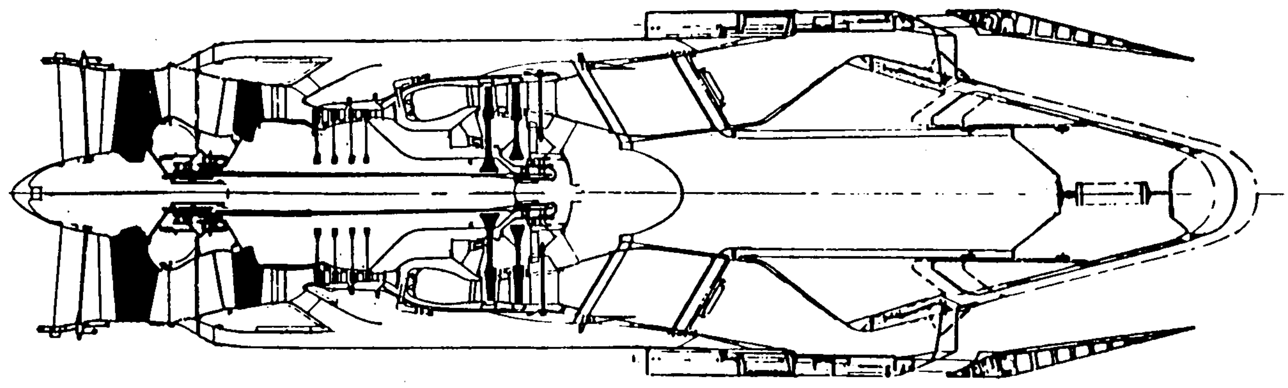


FIGURE 19. MACH 5.0 LIFT/DRAG

The Mach 5.0 baseline engine is the GE variable cycle turbofan/ramjet engine, also referred to as a variable cycle hypersonic jet (VCHJ) using LNG fuel. The VCHJ (Figure 20) is a new engine concept defined by GE in 1985 from NASA-sponsored supersonic transport studies during the late 1970s. The engine is an afterburning dual-rotor turbofan that combines double-bypass, variable-cycle engine features with high Mach flow enhancement concepts. GE estimated a sideline noise of approximately 112 dB, or 10 dB in excess of the Stage 3 limit. Several engine operational modes are possible through the following features:

- Low specific thrust at takeoff for noise reduction, with high-thrust capability through augmentation
- Maximum climb and acceleration thrust during subsonic cruise and transonic operation
- High-thrust windmilling (ramjet) operational modes plus efficient hypersonic cruise capabilities
- Very good part-power subsonic cruise and loiter capabilities

The turbofan core engine of the VCHJ is based on the double-bypass, variable cycle engine (VCE) developed by GE during studies of supersonic propulsion technology. The VCE core employs a low-temperature augmentor for supersonic acceleration. Noise constraints preclude the use of the augmentor at takeoff;



ENGINE SHOWN WITH AXISYMMETRIC COANNULAR NOZZLE

FIGURE 20. GE MACH 5.0 VARIABLE CYCLE HYPERSONIC JET ENGINE

therefore, the fan has been sized for takeoff and subsonic cruise requirements without augmentation. The variable cycle features that give the VCE core improved flexibility over conventional mixed flow turbofans include:

- Split fan (outer) bypass duct with variable inlet guide vanes
- Fan variable area bypass injector
- Exhaust variable area bypass injector
- Variable area low-pressure turbine
- Core-driven rear fan block
- Variable area exhaust system with inverted velocity profile during takeoff

The turboramjet essentially phases out the turbomachinery during very high-speed operation. A ram air bypass duct is located around the basic engine, and a special stream control valve similar to a GE patented variable area bypass injector (VABI) is employed to allow smooth transition from turbojet to ramjet mode above Mach 3. Key parameters are:

• Overall pressure ratio	25
• Turbine rotor inlet temperature	4,000°F maximum
• Bypass ratio	1.50
• Fan pressure ratio	5.5

A variable geometry two-dimensional inlet was selected, both the inlet and nozzle are designed for Mach 5.0 at an altitude of 83,000 feet. The four engines are mounted in a Quad Pod propulsion module on the fuselage lower centerline. The engine installation is aerodynamically integrated with the fuselage. The Quad Pod inlet includes movable ramps and a transition section with both bypass air and pressure surge dumps. A single expansion ramp nozzle (SERN) has been incorporated allowing for a high degree of propulsion system integration with contoured nozzle upper surfaces formed by the aircraft lower surface. The GE nozzle design does not include an ejector due to the SERN, and hence it resembles a chute suppressor nozzle.

The engine compartment houses four separated engines and contains provisions for fuel lines, secondary power-generating equipment, cooling air ducting, compartment ventilation, and fire protection. Engines will be sealed to the inlet and nozzle ducts with flexible metal bellows.

The alternate Mach 5.0 engine is the Aerojet TechSystems two-spool air turboramjet (ATR) using LNG. Aerojet initially proposed a conventional dual regenerator ATR where the incoming fuel is heated regeneratively in the combustor and nozzle walls to drive the turbine while providing cooling for these areas. The result was an engine that yielded Mach 5.0 cruise performance equal to or better than that of the GE VCHJ. However, the subsonic performance was significantly less than that of the VCHJ. Aerojet later proposed a two-spool ATR, where a separate auxiliary airbreathing gas generator provides the motivating force for the turbine at flight speeds below Mach 3.0. This results in significantly improved subsonic performance but at additional weight. Although the latest Aerojet TechSystems data show potential for lower takeoff gross weights than for the VCHJ, no comparative analyses were accomplished due to resource limitations.

The maximum temperatures the aircraft will experience range from 460°F to 1,580°F (Figure 21). They are 1,580°F on the nose, 1,200°F on the leading edge of the wing, 1,425°F on the empennage, 920°F on the upper fuselage, and 1,020°F on the lower fuselage.

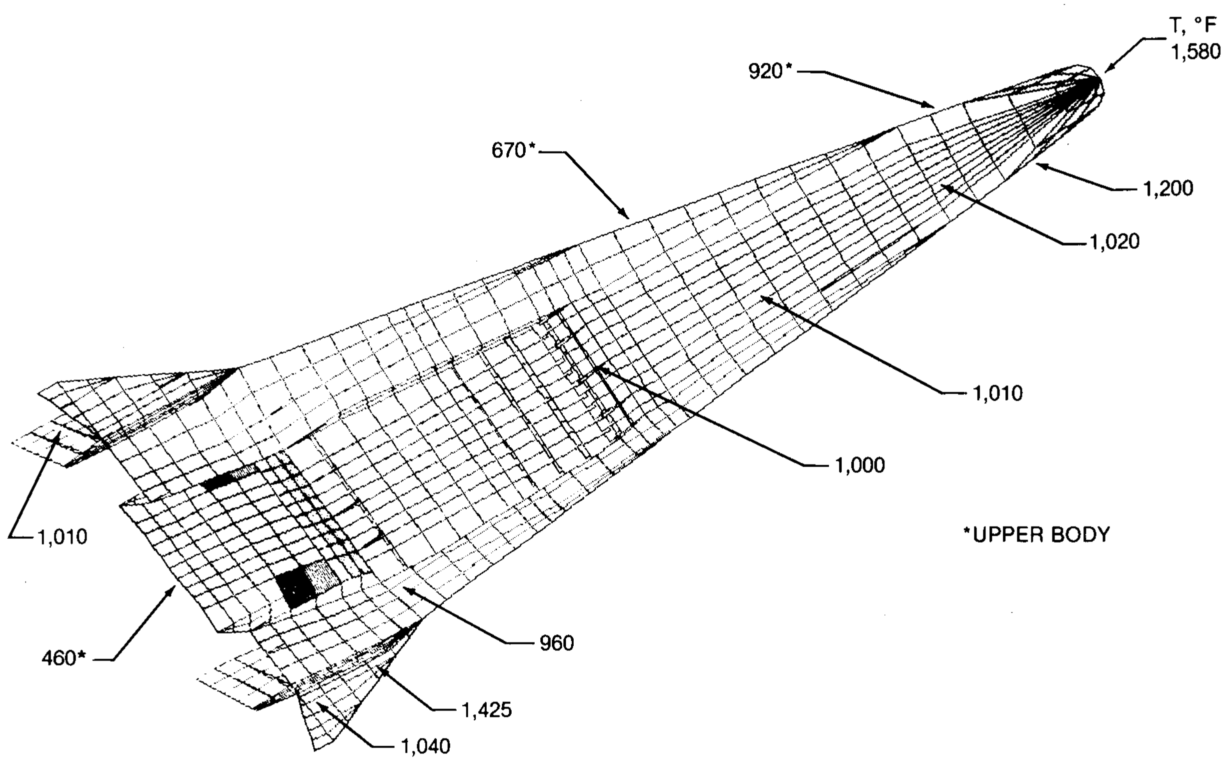


FIGURE 21. MACH 5.0 MAXIMUM TEMPERATURES

Thermal management included both external and internal heat generation and dissipation requirements to maintain energy balance. Fuel was used as the primary heat sink for absorbing energy loads. Except for the engine inlet and nozzle, the aerodynamic heating of the aircraft was regulated by passive TPS employing MMLI. The nonpressurized air gap external to the MMLI of the cabin and fuel tanks experiences low atmospheric pressure associated with flight at high altitudes. Consequently, the Mach 5.0 requires less insulation than the Mach 3.2 concept. The cabin wall consists of a NOMEX honeycomb core with poly ether-ether ketone (PEEK) face sheets as the pressure shell. The cabin insulation criteria included a 70°F cabin air temperature, an 80°F cabin liner temperature. The MMLI was optimized for the minimum total weight considering LNG boiloff, insulation, and tank structure. The throat regions of the Mach 5.0 nozzle and inlet require active cooling. Based on McDonnell Douglas studies, a wall structure is recommended comprised of honeycomb and a skin heat exchanger which serves to transfer heat from inlet air and engine exhaust to the fuel.

Candidate materials consist of titanium (including MMC), René 41, and TD Ni Cr. SCS-6/RSR-Ti, being the most efficient considering specific moduli and specific compressive yield strength, was used for the structural material of the Mach 5.0 concept. René 41 has the highest temperature capability and was used for the wing leading edge. The TD Ni Cr was used for the leading edge of the empennage because of its greater temperature overshoot capability. Considerable work is being done in industry and government, especially NASA's Langley Research Center and Lewis Research Center, to develop these and other advanced materials. Where TD Ni Cr is no longer offered commercially it would only be considered if the R&T program was not successful. McDonnell Douglas has performed high-temperature tests on titanium MMC with success in the Mach 5.0 temperature range.

In addition to the materials for the major components, materials investigations were performed for the major structural elements of the propulsion system, including the inlet ramps, nacelle, exhaust, and exhaust ramps. The Lewis Research Center has developed a ceramic-ceramic material far superior to others. Consequently, it was chosen for the internal structural applications. The external shell of the inlet and nacelles is SCS-6/RST Ti, and Graphite/HFC,TZM was used for the engine/nozzle transition structure.

The same type of loading conditions were examined for the Mach 5.0 concept as for the Mach 3.2 concept. In this case, however, the cruise condition was the critical design case. An FEM was constructed for the Mach 5.0 concept, representing all the structural elements of the aircraft: the spars, ribs, frames, longerons, and shear webs for the major components. The passenger cabin and propulsion system, including inlet, nacelle, and exhaust also are modeled. The FEM included temperatures, materials, and loading conditions. Both deflection and stress were checked to ensure structural integrity. Stress levels, as well as deflections, were within structural allowables.

As in the case of the Mach 3.2 evaluation, several structural concepts were examined resulting in the three best choices; (1) skin-stringer, (2) superplastic formed/diffuser bonded, and (3) honeycomb construction. The selection and optimization of the SCS-6/RSR Ti honeycomb construction resulted in a structural weight reduction of 15 percent relative to the mid-1970s technology studies of high-speed commercial aircraft. The structures weights for the Mach 5.0 concept, including the wing and movable tip, fuselage, and tail sections, were derived from optimization analysis-based commercial aircraft design criteria and standards.

Aircraft systems weights (excluding the TPS and the liquid methane fuel tank) were based on weight data from the Concorde and past NASA/McDonnell Douglas high-speed commercial aircraft studies.

The Mach 5.0 concept system weights reflects assumed improvements due to lighter weight materials and innovative design. The weight of the LNG fuel tank structure is based on optimized structural analysis. Advanced systems such as an all-electric vapor cycle cabin air conditioning and pressurization system, a fly-by-light flight guidance and control system, an all-electric secondary power system, and an all-electric anti-ice system are incorporated. The auxiliary power unit system has been deleted with reliance on airport ground support utilities. In addition, an advanced technology glass cockpit (two-person crew) is assumed, which includes flat panel displays and multiplexed digital data busses. The Mach 5.0 engine weight is based on data received from GE.

The operator items weight represents passenger and galley service to accommodate a three-class, 300-passenger cabin. The payload weight is as follows:

- 300 passengers at 165 pounds each = 49,500 lb
- 40 pounds of baggage per passenger = 12,000 lb
- Mission payload weight = 61,500 lb
- Cargo at 10 pounds per cubic foot = 5,000 lb
- Maximum space-limited payload weight = 66,500 lb

PERFORMANCE AND ECONOMICS

Performance

The HSCT performance was analyzed according to commercial domestic and international aviation rules and practices. The mission profile is depicted in Figure 22 and begins with conventional takeoff and climb out to 10,000-feet altitude. This is followed by an accelerating climb to the cruise Mach number. The climb is continued at cruise Mach number until optimum cruise altitude is reached. The main limitations in climb are the cabin rate of climb and the aircraft excess thrust over drag at the top of climb. Conventional cabin pressure altitude at cruise is 8,000 feet, and the limiting rate of pressurization change is equivalent to 300 feet per minute at sea level. This requires that the climb takes at least 23.5 minutes. A requirement of 4,000-feet-per-minute potential rate of climb was assumed to ensure sufficient acceleration and rate of climb to reach cruise altitude.

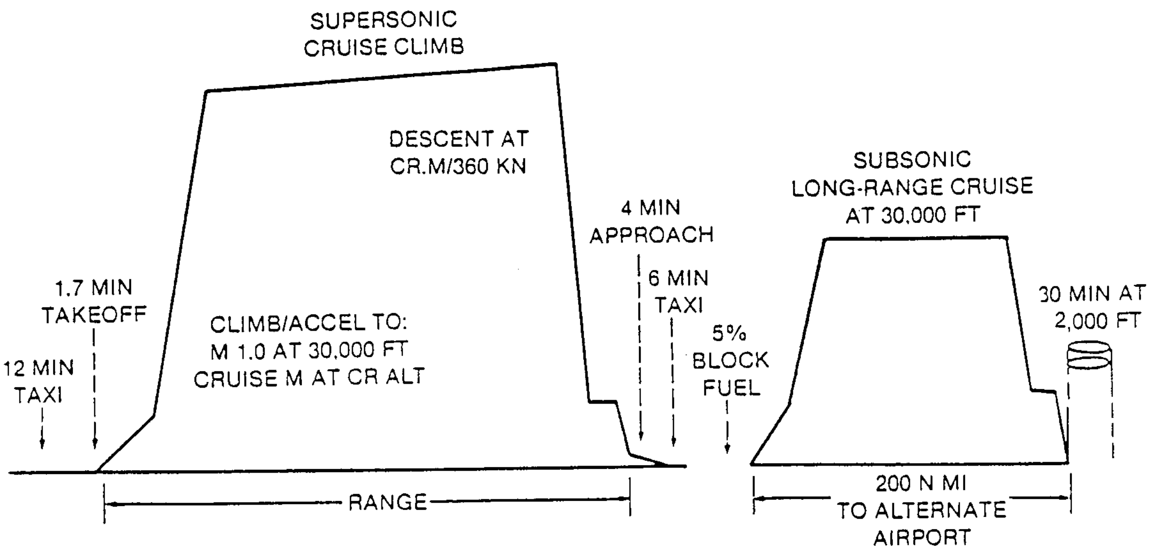


FIGURE 22. MISSION PROFILE

Cruise is flown at constant Mach number and optimum altitude to maximize range. During fuel burn-off the aircraft is allowed to cruise-climb to remain at optimum conditions. The descent is at idle power and constant airspeed, as is the current convention. The cabin rate of descent is limited to 300 feet per minute with idle power.

Below 10,000-feet altitude, regulation-specified speeds of 250 knots are maintained until landing approach at conventional speeds of 140 knots or less. Fuel reserves based on international rules are maintained: 5 percent of block fuel, fuel to fly to an alternate destination of 200 nautical miles, and fuel for a half-hour hold at the 2,000-foot altitude. Sufficient taxi, takeoff, and landing allowances for time and fuel determinations are included.

Winds aloft at the 60,000- to 90,000-foot cruise altitudes of the Mach 3.2 and Mach 5.0 concepts are considerably less than those at the cruise altitudes of subsonic aircraft (35,000 to 43,000 feet). For supersonic vehicles, wind influence on still-air range is less than a tenth of that of subsonic airplanes. Therefore, wind effects are only used for the subsonic reference airplane. The effects of earth's rotation are incorporated in the mission analysis.

Concept sizing was accomplished by varying wing reference area and engine size, and taking into account constraints and margins as appropriate. These constraints are: (1) takeoff field length of 11,000 feet or less, (2) landing approach speed of 140 knots or less, and (3) cruise at optimum altitude or at the operationally determined ceiling. The minimum value of design takeoff gross weight satisfying these constraints determined the wing/engine size combinations.

The economic analysis included an advanced subsonic transport with year 2000 technology. The airplane was sized for 300 passengers and 7,400-nautical-mile still-air range. (The design range of 6,500-nautical-mile geometric distance was corrected for prevailing westerly headwinds across the northern Pacific.) The wing and engines were sized by an initial cruise altitude for maximum range and cruise-power ceiling altitude. The maximum takeoff gross weight is 397,000 pounds, with a takeoff field length of approximately 7,000 feet and landing approach speed of 130 knots.

Due to operational uncertainties regarding overland operations, two configurations were developed for Mach 3.2. The D3.2-3A configuration was optimized for supersonic flight with minor compromises for low-speed flight (takeoff and landing). The D3.2-4B configuration was compromised for subsonic flight over land. For the 6,500-nautical-mile design mission, the -3A was sized at a maximum takeoff gross weight of 769,000 pounds, and the -4B was sized at an MTOGW of 880,000 pounds. A representative city-pair was selected to illustrate the impact of disallowing supersonic flight over land. The New York-Tokyo market is second largest in terms of international revenue passenger miles (rpm) and thus presents an aircraft sizing focal point. If supersonic flight over land could be achieved, the HSCT great circle distance would be 5,846 nautical miles. If supersonic flight over land is disallowed, a different routing would be expected to minimize flight time by reducing the distance over land from 4,526 nautical miles to 2,518 nautical miles for the subsonic operation. This route has an overall distance of 6,236 nautical miles; the subsonic flight segment represents 40 percent of the total flight if the HSCT is diverted from the great circle route to achieve minimum flight over land (Figure 23).

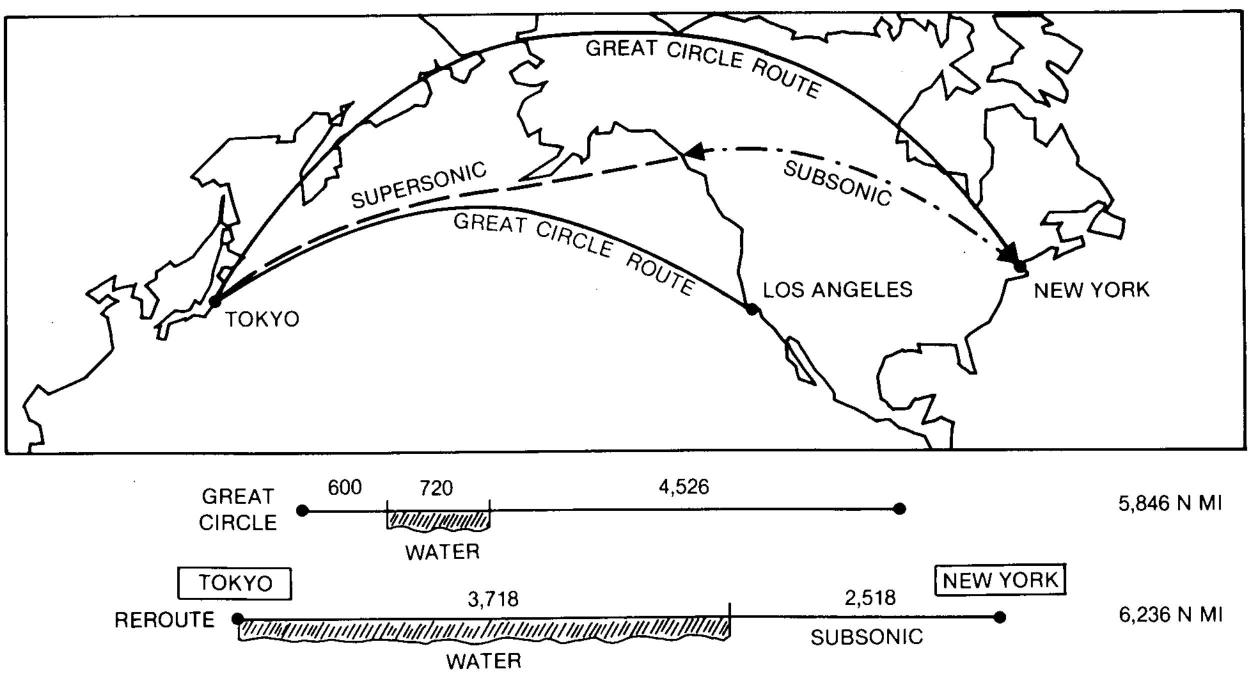


FIGURE 23. KEY OVERLAND MARKET NEW YORK-TOKYO

To illustrate the effect of subsonic flight segments, the -3A and the -4B concepts were sized to 6,500-nautical-mile range with up to 40-percent subsonic legs. Figure 24 shows the increased maximum takeoff gross weight for the -4B concept for the all-supersonic design mission. This is a result of greater structural weight due to the larger aspect ratio and the lower aerodynamic efficiency at supersonic cruise. However, with increasing subsonic flight distances, the supersonic design is penalized with increased maximum takeoff gross weight as contrasted to the improved subsonic configuration. Consequently, for subsonic legs greater than 27 percent of the total range (approximately 1,750 nautical miles), the -4B concept is lighter than the -3A configuration.

The best range of the Mach 5.0 concept was 3,900 nautical miles with a maximum takeoff gross weight of 1,213,000 pounds (meeting the takeoff field length requirement of 11,000 feet). With this limited range capability, an economic comparison with other vehicles is not possible; therefore, technology improvements are assumed to produce a vehicle capable of a 6,500-nautical-mile range. Early Mach 5.0 configuration studies showed a promising lift-to-drag ratio of 6.25 compared to 5.4. Further configuration development is expected to lead to lift-to-drag levels of 6.75. This corresponds to a 20-percent decrease in drag. Further, considering that

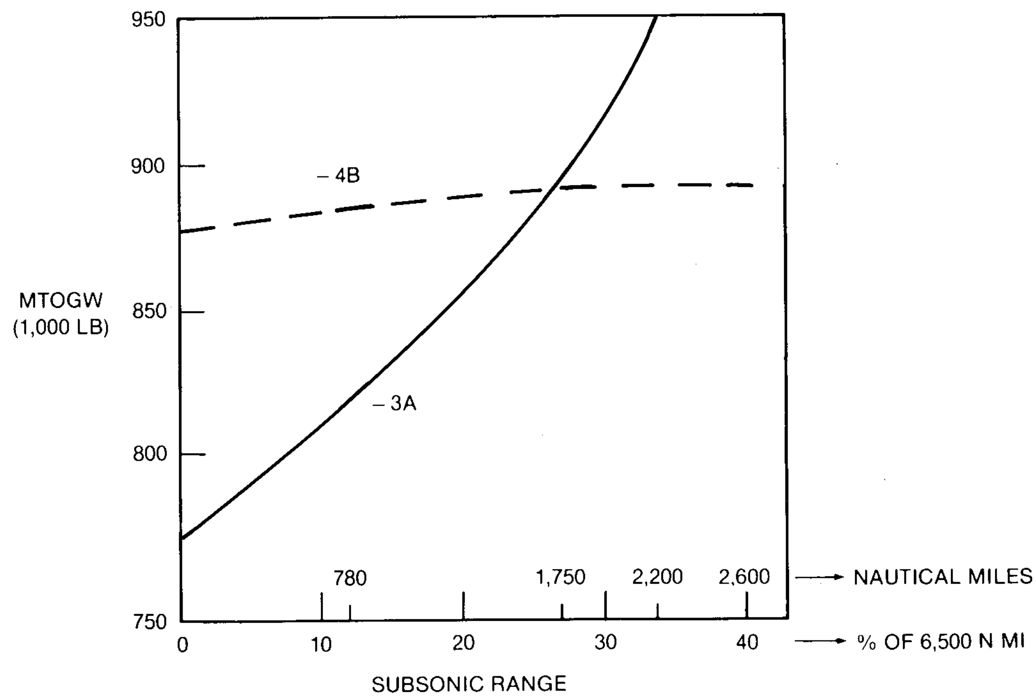


FIGURE 24. MACH 3.2 CONCEPT SIZINGS FOR PARTIALLY SUBSONIC RANGE

the Mach 5.0 engine efficiency is 13 percent below the potential level, a 10-percent decrease in fuel flow was applied. These technology advancements would have later technology readiness dates. With these improvements in drag and fuel efficiency, the Mach 5.0 concept with a takeoff gross weight of 1,213,000 pounds achieves the 6,500-nautical-mile design mission with a takeoff field length of 8,600 feet. In retrospect, Mach 5.0 can be achieved with LNG fuel (heat sink potential for the greater aerodynamic heating compared to Mach 3.2); however, the energy level of LNG is not adequate to meet performance requirements.

Weight comparison of the Mach 3.2 and 5.0 baseline concepts is shown in Figure 25. The dominating weight fraction is the fuel. To reduce the takeoff gross weight and make the HSCT more viable and competitive, the fuel fraction must be reduced considerably. Future HSCT studies should address innovations in drag reduction, propulsion system inlet and nozzle design, engine cycle, and structural concepts providing safe, maintainable, and reliable components that produce reduced fuel fractions.

Figure 26 depicts the overall fuel efficiency in terms of pounds of fuel per available seat-nautical mile to enable comparison with other airplanes, such as the 108-seat, Mach 2.0 Concorde. The Mach 3.2 concept, through year 2000 technology, would be expected to provide a 50-percent reduction in fuel requirements per seat compared to Concorde. The values given are 3,500 nautical miles as a representative system average length of all-supersonic range and of the split half-subsonic, half-supersonic flight. The Concorde data are for the 3,000-nautical-mile range. Values for the DC-10 (277 seats) and 747 (365 seats) are shown as 1970's subsonic data.

Economics

Figure 27 details the commercial value assessment procedure developed during this study. Interactions between HSCT characteristics, market parameters, economics, and competitive factors are noted in simplified format. Basic assumptions include: (1) supersonic flight over land is disallowed, (2) passenger market is segmented into four fare classes, (3) seating is based on the onboard passenger mix, and (4) fuel price is station-specific. All costs are expressed in 1987 dollars.

The traffic model under the speed over land restriction consists of eight regions — a subset of the unrestricted model. Europe-to-Africa and Europe-to-the-Far-East were eliminated because all routes involved long subsonic distances. Analysis of a Tokyo-based airline indicates a 10- to 15-percent productivity loss due to the overland restriction. Similar analysis of a Paris-based system showed 7- to 28-percent losses. These results are

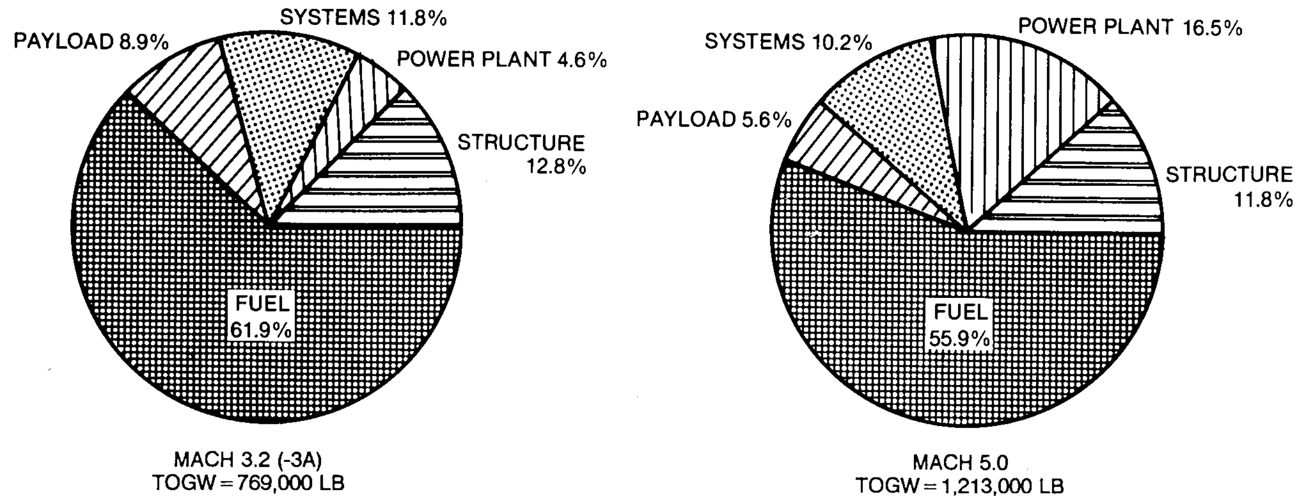


FIGURE 25. WEIGHT BREAKDOWN

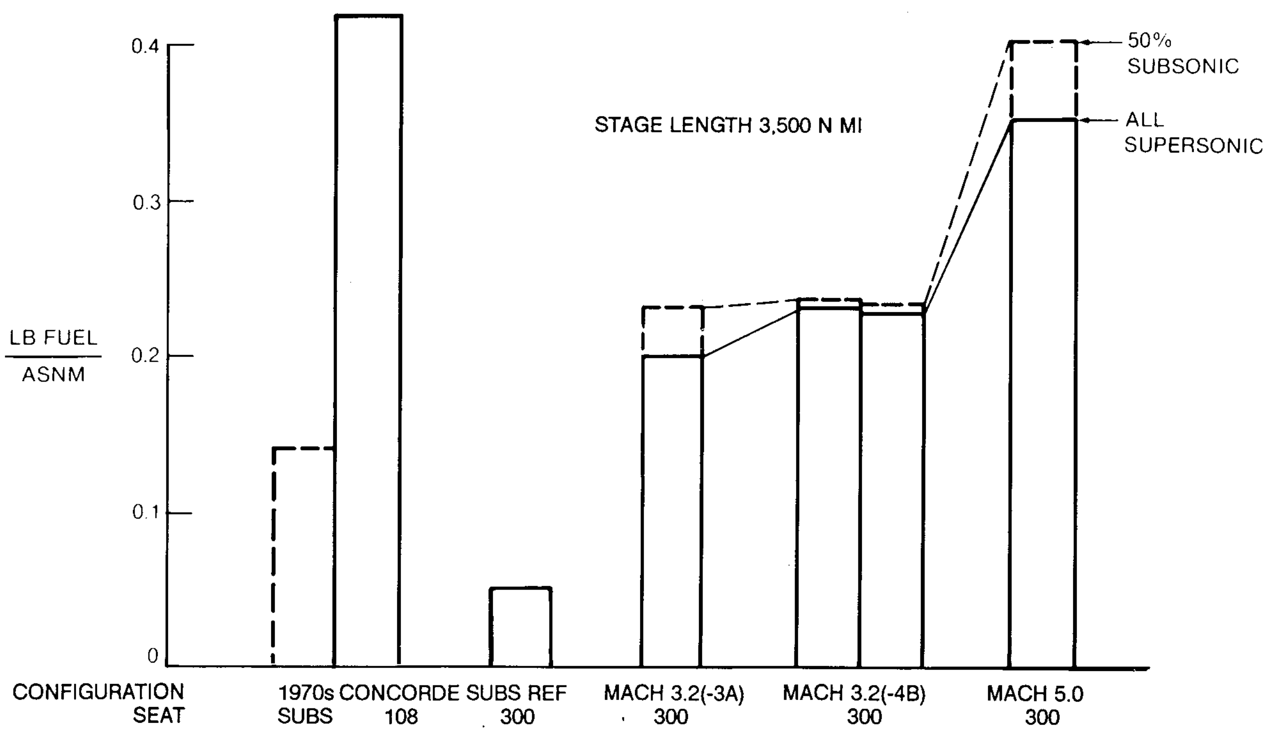


FIGURE 26. FUEL EFFICIENCY

corroborated by MIT, indicating an 8- to 20-percent loss in productivity. Productivities from the Douglas computer model show a 10- to 15-percent loss compared to the potential supersonic flight over land. The speed restriction reduces productivity, which reflects two significant factors. First, city-pairs with long distances over land may not be flown in the restricted case because they exceed the range capability (reduced because of the subsonic cruise requirement). These city-pairs are precisely the ones for which the potential penalty is greatest. Secondly, the restriction causes rerouting to avoid land masses. Although the diverted flight path is longer, it

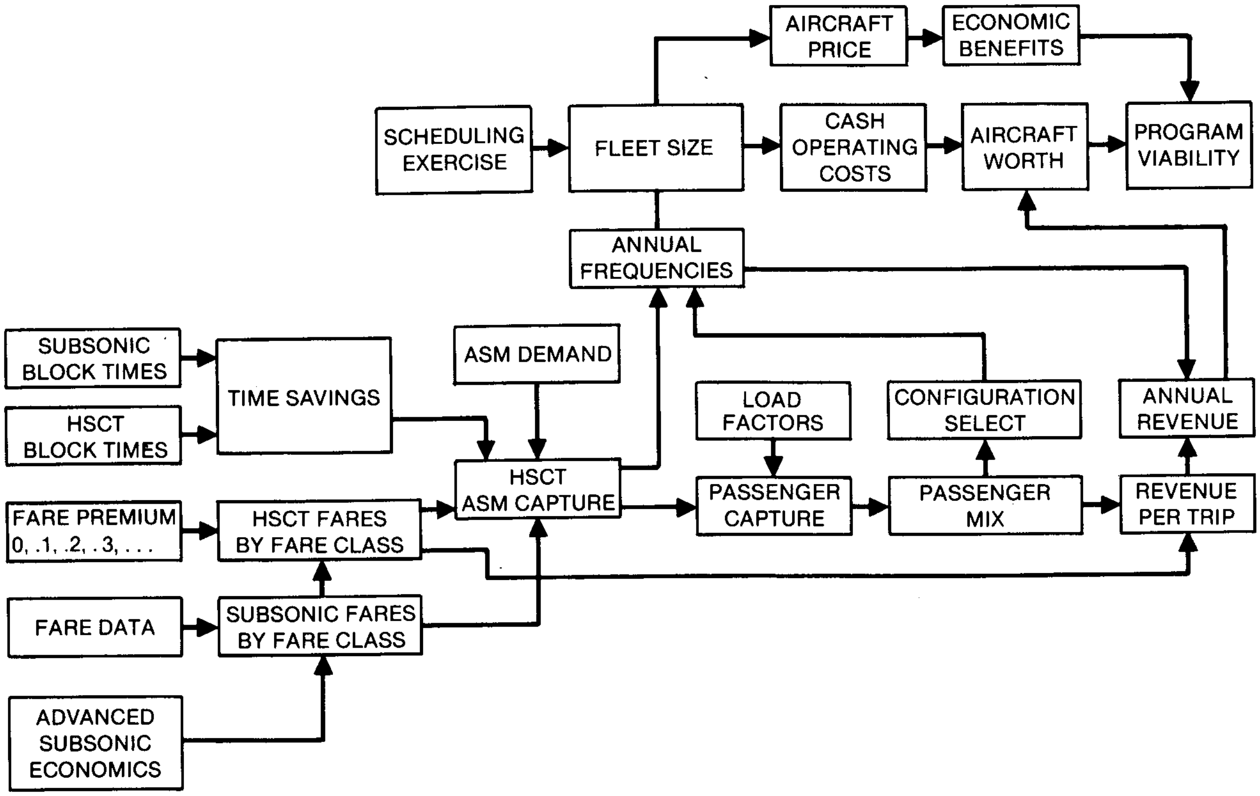


FIGURE 27. ECONOMIC AND MARKET STUDY MODEL

is flown at high speed and the flight time is favorable compared to that of the great circle, subsonic flight paths. Finally, whether aircraft cruise over land at subsonic speed or fly a longer path to avoid land or a combination of the two, blocktime is certain to increase. Each city-pair (no flights under 2,000 statute miles) in the eight-region model was studied to estimate the length of subsonic and supersonic cruise legs and to devise a better route that minimizes overland travel. City-pairs under 2,000 statute miles tend not to be very good HSCT candidates, because block-time savings over subsonic aircraft are not significant at short ranges.

Forecast scenario 2 traffic levels were assumed. The North Atlantic and Pacific routes are the most important with the Pacific becoming the greater after the year 2000. During the period 2000 and 2025, the projected growth in the Pacific will be more than twice that of the Atlantic. Thus, the design range should be established so that the HSCT should be able to perform most of the transpacific segments. A range of 6,500 nautical miles will permit flying from Sydney to the west coast of North America. Ten-percent traffic stimulation is assumed, (i.e., 10 percent of the dollar value of the passenger's time savings, excluding fare premium, is used to purchase additional trips). The advanced subsonic airplane is in competition with the HSCT in terms of market capture.

The operating cost components follow CAB Form 41 format for direct and indirect cash costs. These are: flying operations, maintenance, passenger service, aircraft and traffic servicing, promotion and sales, and general and administrative. Cost estimates are computed by Douglas operating cost formulas. Information generated during the study includes fuel costs and fuel infrastructure costs, and maintenance cost. Fuel costs (i.e., feed stock prices) were determined through industry-wide workshops. Fuel handling costs, including special facilities where required, resulted from fuel facility sizing and costing studies performed by engineering companies experienced in such projects. The results are shown in Figure 28. Airframe maintenance cost predictions utilized labor-hour and material cost data for eight large, commercial transport aircraft and the estimated effect of future high-speed civil transport technologies. Airframe maintenance labor-hour and material cost data were analyzed to determine the most maintenance-intensive operating systems by ATA chapters. Concorde maintenance information was used subjectively due to its unique operating environment; small fleet size, limited support, high occurrence of unique operations (charters), spare parts available, and limited technical

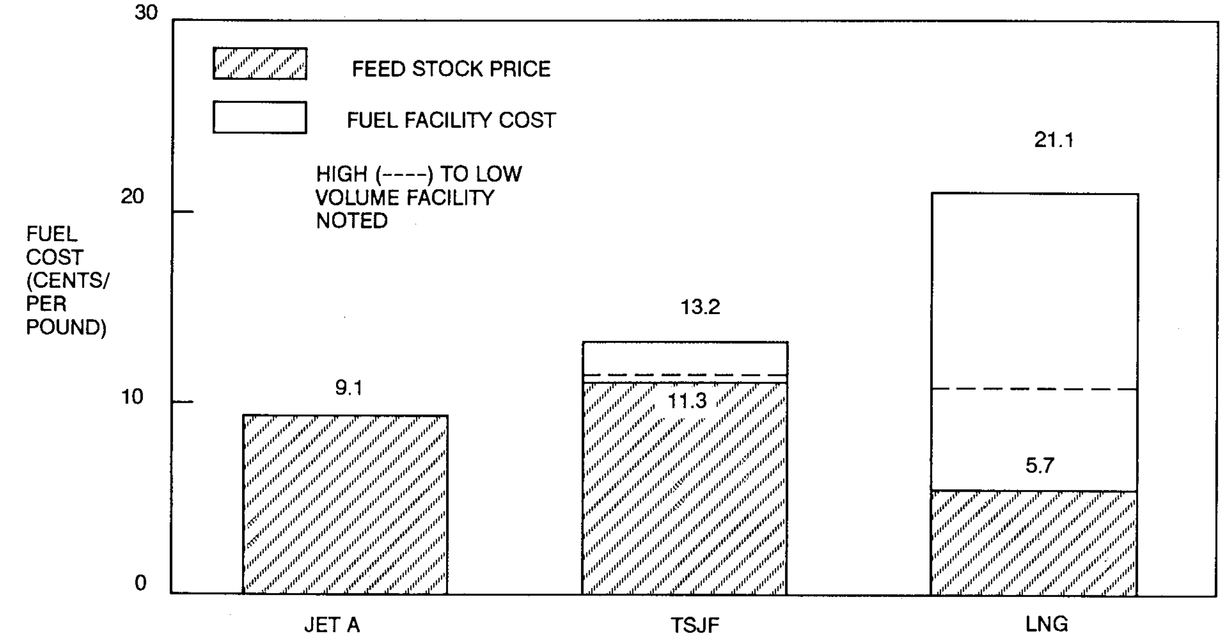


FIGURE 28. FUEL COST

support. The X-15 and SR-71 were analyzed to determine peculiar support requirements. Engine maintenance costs were derived by Douglas from data provided by P&W and GE.

Figure 29 shows the cash operating costs for the Mach 3.2 and Mach 5.0 aircraft and for the advanced subsonic aircraft of the same size. Ownership-related expenses are not included because cash flow over the life of the HSCT is used to compute its value as an investment. The Mach 3.2 aircraft cash operating costs on a per seat-mile basis are estimated to be approximately 30 percent higher than for the subsonic transport. The Mach 5.0 aircraft is estimated to have a cash operating cost approximately 140 percent higher than the subsonic transport. Comparison of the DOC per seat-mile to the hourly costs highlights the value of speed and underscored the need to achieve supersonic cruise overland operations.

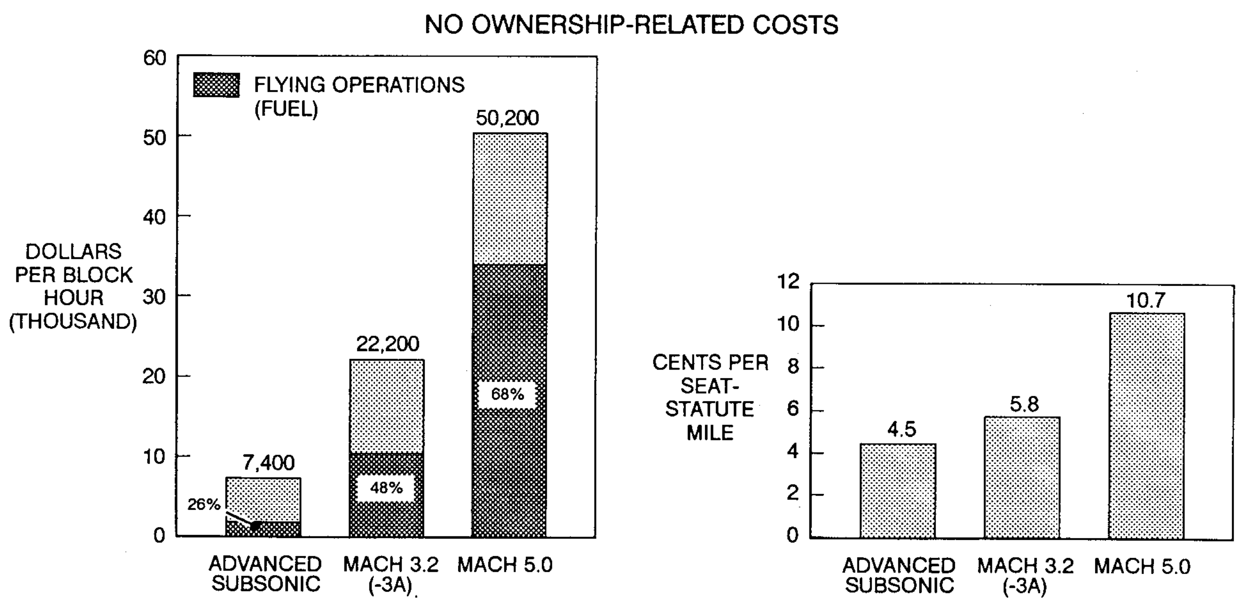


FIGURE 29. AIRCRAFT OPERATING COSTS

Passenger revenue is based on published International Civil Aviation Organization (ICAO) fare data, fare premium assumptions, and corresponding HSCT market share statistics. The passenger market is assumed to consist of equal numbers of business and personal travelers. Both the business and personal components are segmented by fare classes. Each fare class has its own average value of time and fare level (related to ICAO full fares). As fare premium increases, the HSCT market share is reduced. Almost all of the fare-sensitive traffic will be lost to subsonic aircraft at 10- to 20-percent fare premium while 50 percent of the first-class and business-class passengers would remain with the HSCT at 30-percent fare premium. Yield (cents per passenger-mile) is improved because fares increase and the onboard passenger mix changes to favor the higher yield business and first-class passengers.

Effective yields are significantly different from what might be predicted from load factors and published fare. Frequent flyers, upgrades to first class, nonrevenue passengers, and special low fares from interline agreements cause the effective yield to be diluted and significantly lower than that predicted from load factors and ICAO fares. The revenue based on ICAO fares is adjusted such that an advanced MD-11 would have an investment value (aircraft worth) equal to its selling price. This ensures that the HSCT revenues are based on real-world yields and that HSCT aircraft worth estimates are consistent with the market price of a known airplane. Figure 30 illustrates the annual revenue-generating capabilities of the Mach 3.2 and Mach 5.0 concepts with the Mach 5.0 concept generating approximately 10 percent greater revenue.

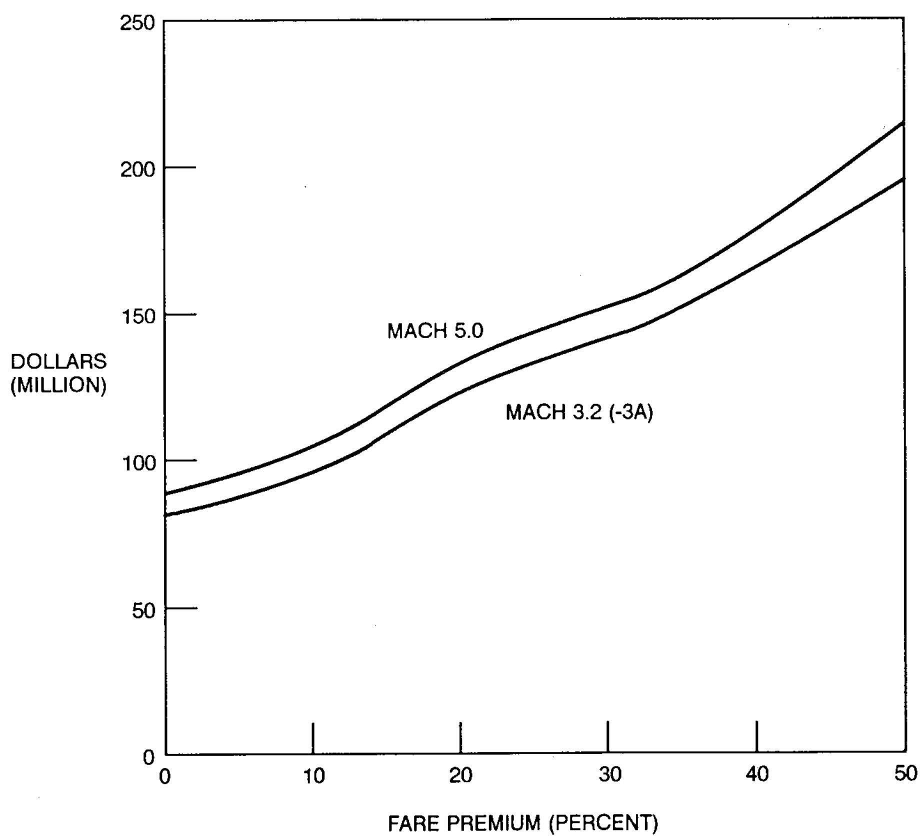


FIGURE 30. ANNUAL REVENUE

Aircraft worth is the investment value of an airplane to the airline operator. The worth of an HSCT is estimated by a process that determines the price to the operator (i.e., airline) so that a target rate of return on investment is achieved by the operator. This process includes 1987 tax law and depreciation schedules, life of the asset, and, most importantly, the annual operating cash flow. All of the airplane characteristic such as size, weight, speed, lift-to-drag ratio, propulsion efficiency, and other parameters are embodied in the cash-flow estimates. Also involved in the cash flow (and hence, aircraft worth) are operational parameters such as utilization, turnaround time, passenger mix, load factor, fare differences in various regions of the world, and fare premium.

Results are shown in Figure 31 highlighting the significant advantage estimated for the Mach 3.2 aircraft compared to the Mach 5.0 aircraft — $200 million turnaround.

Aircraft prices were developed using the total McDonnell Douglas base of experience and knowledge in the field of high-speed technology and support efforts (e.g., materials, processes, and the like) to the maximum extent. Labor and material resources were estimated on a discrete evaluation basis. Resources were estimated by major aircraft system/component and by functional category. Figure 32 illustrates the Mach 3.2 concept production breakdown. Development costs included all of the necessary resources and tasks required to design, develop, produce, and demonstrate an aircraft that can be FAA certified. Labor hours were translated into constant 1987 dollars using the aerospace fully-burdened labor rates for the different categories of labor (e.g., Engineering, Tooling, Quality Assurance, and so on). Material and equipment were estimated separately with propulsion system costs furnished by GE and P&W. The end product of the estimating process is a flyaway cost (price) in which the development cost is amortized over the production program including the manufacturer's targeted rate of return.

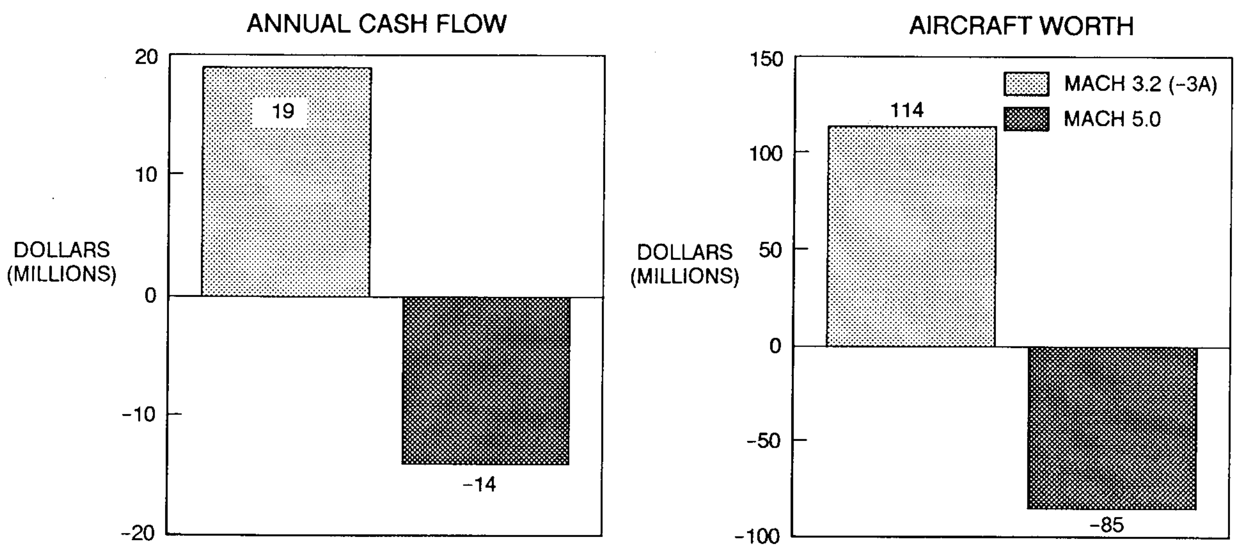


FIGURE 31. HSCT ECONOMICS AT ZERO FARE PREMIUM

Necessary conditions for economic viability include: (1) airplane revenues covering operating costs plus an attractive rate of return to the operator, (2) fares low enough to provide competitive HSCT service, and (3) a market large enough to permit a selling price lower than the investment value of the airplane. The evaluation procedure places the HSCT in competition against the advanced subsonic airplane on a city-pair basis. This ensures that the HSCT is applied to those markets in which it performs best. Repetition of this procedure for various fare levels will determine whether the foregoing conditions can be simultaneously satisfied. Production to satisfy the market for the period 2000 to 2025 ranges from over 1,500 (zero fare premium) to 250 units (at approximately 40-percent fare premium). The Mach 3.2 aircraft becomes economically viable at 25- to 35-percent fare premium. Results are shown in Figure 33.

The Mach 3.2 (-3A) concept is potentially viable with a fare premium of 30 percent (500 units). These data show that the Mach 5.0 concept is not economically viable at any fare premium. Figure 34 shows potential increases in aircraft worth based on technology improvements to both airframe and engine as well as operational improvements through supersonic overland flight and reduced turnaround time. This, together with a modest fare premium, increases aircraft worth to approximately match the estimated Mach 3.2 concept flyaway price.

The HSCT promises economic benefits including higher levels of U.S. gross national product (GNP), a better balance of trade, and increased employment. The size of these benefits depends upon the size and timing of the effort from research through production and delivery. They also depend upon the ability of the economy to absorb the increased spending. Generation of great magnitudes of spending over too short a period of time will lead to displacement of other business investment (crowding out), higher interest rates, and increased inflation. A moderately sized program, however, will generate favorable changes in the economy. Historically, for

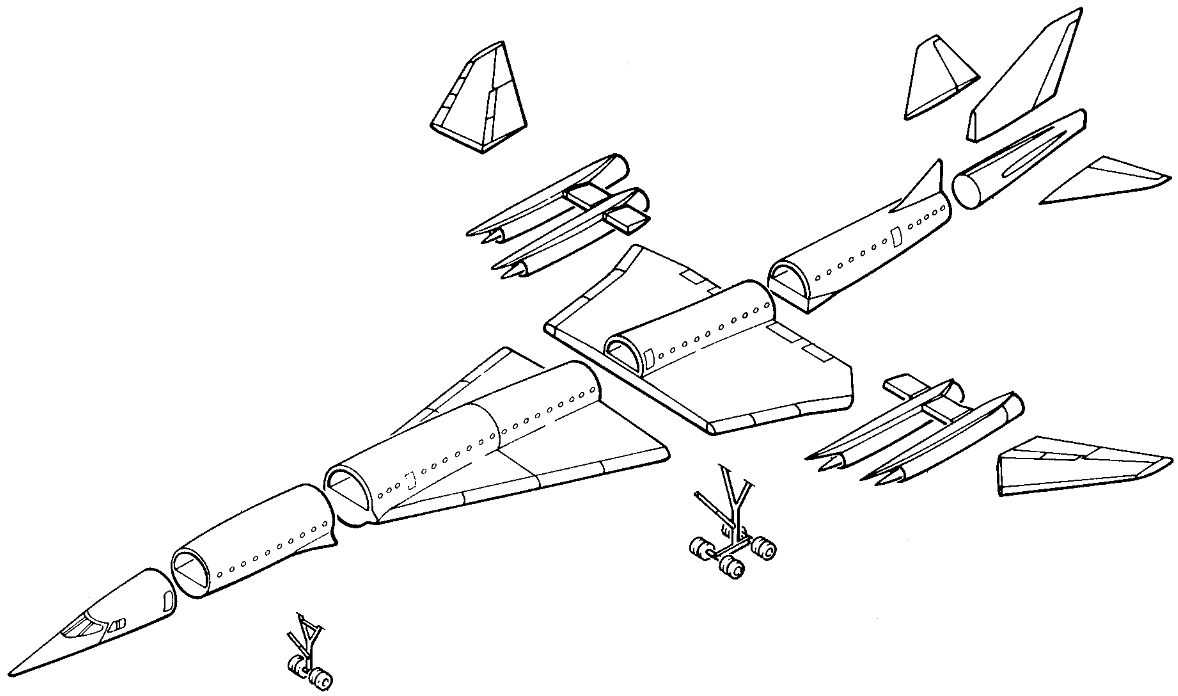


FIGURE 32. MACH 3.2 CONCEPT PRODUCTION BREAKDOWN

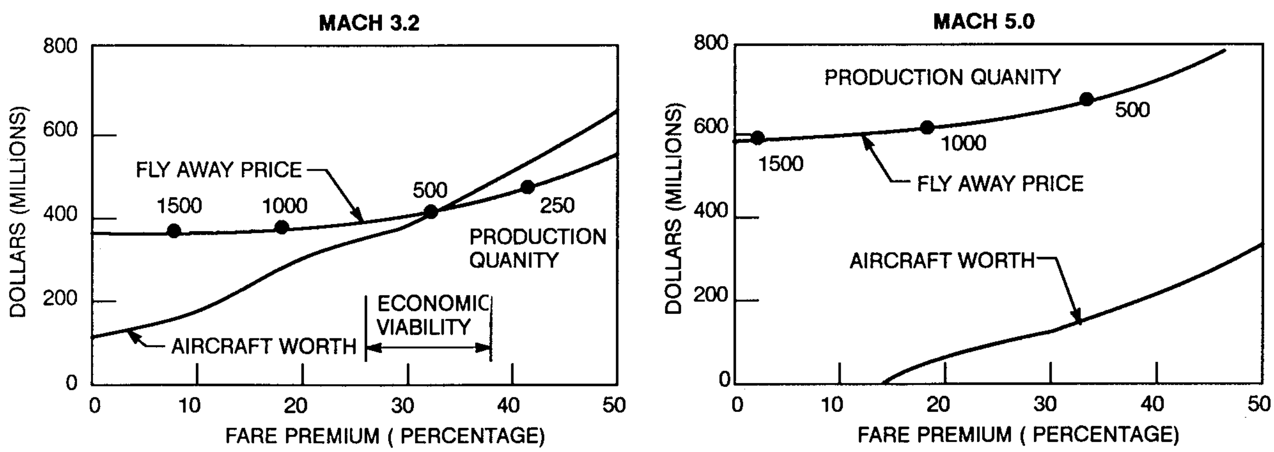


FIGURE 33. HSCT WORTH/PRICE COMPARISON

every dollar of direct expenditures in the U.S. aerospace industry, approximately \$1.20 of indirect gross national production occurs. This results in a total effect of \$2.20 on GNP for every \$1.00 spent on aerospace. The multiplier of 2.2 incorporates a normal amount of crowding out. For every new aerospace job created by the HSCT, there will be other indirect jobs created. It is estimated that each direct aerospace job will lead to about 1.5 indirect jobs resulting in an employment multiplier of 2.5. There can be a crowding out effect in employment; if the unemployment rate becomes too low, then wages will be bid up and inflation and unfilled jobs may result. None of the scenarios considered here, however, seem likely to present significant dangers of employment crowding out, given a baseline prediction of 5-percent unemployment in 2013.

Several of the key parameters of the economic benefits analysis have been identified. In order to bound the problem numerically, a range of values is assumed for some of the key parameters: (1) total production is

POTENTIAL IMPROVEMENTS

- GROSS WEIGHT REDUCTION: $52M
- IMPROVED ENGINE EFFICIENCY: $28M
- JET "A" FUEL SPECIFICATION: $35M
- SUPERSONIC CRUISE OVERLAND: $50M
- 1-HOUR TURNAROUND: $35M
- HIGHER COACH/DISCOUNT COACH RATIO: $45M

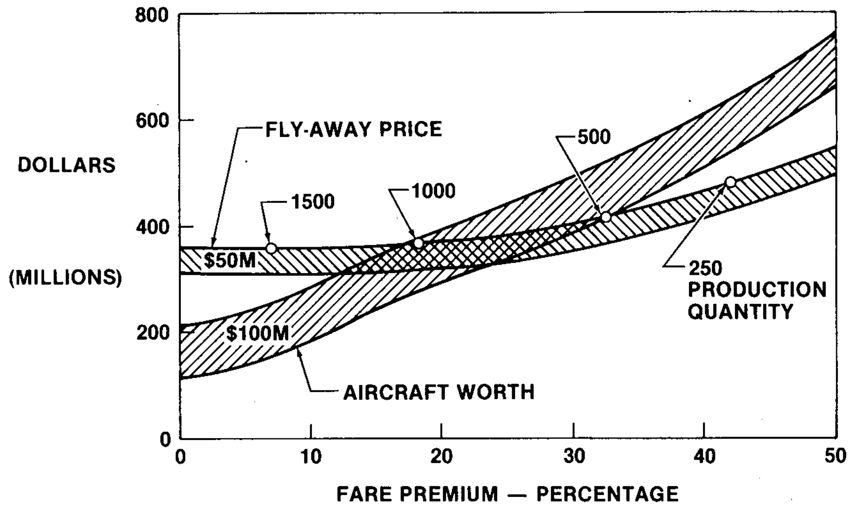


FIGURE 34. MACH 3.2 ECONOMIC VIABILITY

500 and 1,000 aircraft; (2) unit production cost is $322 million and $301 million; (3) development cost is $14.4 billion; (4) domestic content is 50 percent, 70 percent, and 85 percent of production cost (Figure 35). Also, it is assumed based on past U.S. commercial aircraft programs that 73 percent of the aircraft sold are exported. Assuming 70-percent U.S. production, a 1,000-unit program would create more than 400,000 jobs at peak employment and produce a gain in GNP of nearly $500 billion, resulting in more than a $100 billion improvement in the balance of trade. The peak effect on GNP occurs in 2013 when production levels first reach their highest level. The sum of the improvement in the U.S. balance of trade increases very sharply with the percent of U.S. production.

Very large programs with effects in excess of 0.5 percent of GNP may dampen the growth through crowding out and result in multipliers considerably less than 2.2. Scenarios 5 and 6 fall into this category. All of the scenarios show an improvement in balance of trade. In perspective, so long as 30 percent or more of the production of the HSCT is performed in the U.S., the project will improve the balance of trade. The analysis of the balance of trade effects treats only direct effects of importing and exporting.

Technology Availability Dates

As stated previously, this study assumes an HSCT certification date of 2000/2010 with a TAD of 1995/2000. An overall perspective of technology effects on HSCT gross weight relative to 1990 (current) technology is presented in Figure 36. Ten-year technology advancements (year 2000 versus 1990) are projected to result in a 27-percent TOGW reduction. Of this, 13 percent is attributed to the utilization of aluminum metal matrix composite structure (ALMMC), a 5-percent improvement from the application of a partial wing LFC system for drag reduction improvement, a 6-percent improvement reflecting improvements in engine thrust-to-weight ratio and improved SFC, and a 2-percent improvement for aircraft systems technology weight improvement. Figure 36 shows a further takeoff gross weight reduction of 20 percent based on year 2010 technology; a full chord LFC system accounts for an additional 10-percent weight improvement, 6 percent would be provided by innovative improvement in engine T/W and SFC, and approximately 4-percent weight reduction is achieved by innovation in aircraft systems and structural design.

Identification of key propulsion-related technologies that affect the HSCT through the potential for achieving HSCT economic viability and environmental acceptability was a key element of this study. All three engine companies (GE, P&W, and Aerojet TechSystems) provided inputs and projections for future improvements. For the baseline, an FAA certification date of 2005/2010 was assumed, with projections beyond that to an FAA certification date of 2015/2020. Technology areas that could result in reduced TOGW include improved cycle performance, both at subsonic and supersonic cruise, and reduced engine weight (increased thrust/weight). The two items are directly related to economic viability.

	SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4	SCENARIO 5	SCENARIO 6
R&T EXPENDITURES ($ BILLION)	←	$14.4	→	←	$14.4	→
UNITS PRODUCED	←	500	→	←	1,000	→
PRODUCTION COST PER AIRPLANE ($ MILLION)	←	$322	→	←	$301	→
PERCENT U.S. PRODUCTION	50	70	85	50	70	85
PEAK EMPLOYMENT GAIN	167,000	234,000	284,000	312,500	437,500	531,000
PEAK DECREASE IN UNEMPLOYMENT RATE (FROM BASE RATE OF 5 PERCENT)	0.11	0.16	0.19	0.21	0.29	0.35
TOTAL GNP GAINOVER PROGRAM LIFE ($ BILLION)	$209	$280	$333	$363	$495	$595
PEAK GNP GAIN — YEAR 2013 ($ BILLION)	$14	$20	$24	$26	$37	$45
PERCENT INCREASE IN GNP — YEAR 2013	0.17	0.23	0.28	0.31	0.44	0.53
TOTAL IMPROVEMENT IN BALANCE OF TRADE OVER PROGRAM LIFE ($ BILLION)	$37	$69	$92	$69	$129	$175

FIGURE 35. MACH 3.2 HSCT BENEFITS TO U.S. ECONOMY

P&W conducted a subsonic performance improvement study for the VSCE in terms of the major cycle parameters — fan pressure ratio, bypass ratio, overall pressure ratio, and combustor exit temperature. Study results showed that increasing overall pressure ratio offered the best potential for improvement in subsonic SFC but the improvement was only 1.4 percent. GE performed a similar study for its Mach 3.2 VCE, examining the effects of control schedules optimized for Mach 0.95 cruise. This indicated a potential reduction in SFC from 0.5 to 2.0 percent. It is concluded that other approaches must be taken to reduce aircraft subsonic fuel consumption.

Both engine companies were requested to provide projections of SFC improvements assuming better technology. These improvements would be achieved through component efficiency increases, reductions in cooling air requirements, improvements in burner efficiency, and reductions in nozzle unburned air. Increased material temperature capability to reduced losses and better heat transfer formed the bases for these projections to increase engine thrust/weight, thus reducing TOGW. Projected SFC reductions (5 percent subsonically, 3 percent at Mach 3.2) would result in an approximate 6-percent TOGW reduction for the all-supersonic cruise mission and 11-percent TOGW reduction for the mission with 2,000-nautical-mile subsonic cruise segment over land.

P&W has established a goal of a 10- to 15-percent improvement in engine T/W based on three major improvement areas:

- Materials technology
- Cooling system technology
- Turbine technology

An additional 10-percent improvement would be achieved if the design jet velocity could be increased to 2,800 feet per second and still satisfy FAR Part 36, Stage 3 noise requirements with no additional nozzle weight penalty. Combining these two projections and including an allowance for additional noise-suppression devices,

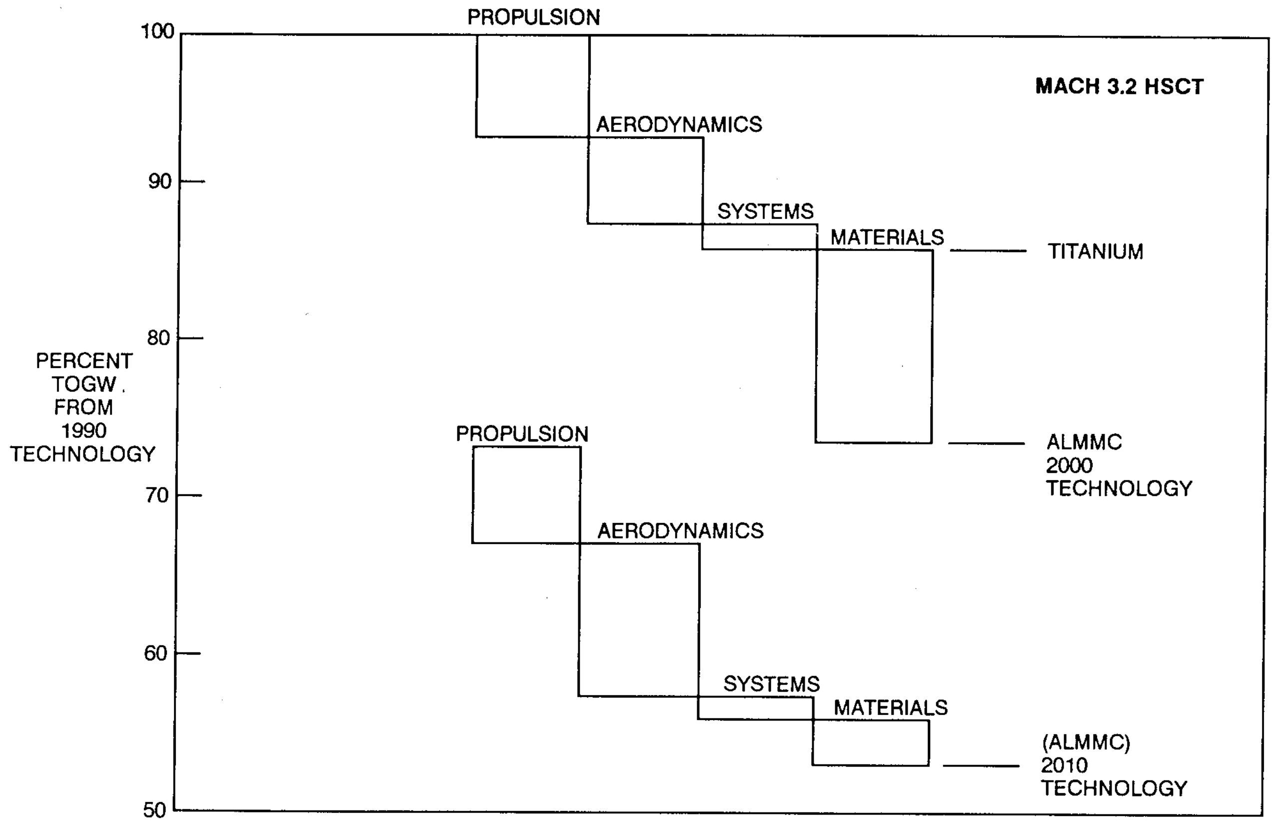


FIGURE 36. PROJECTION OF POTENTIAL WEIGHT REDUCTION

an overall increased thrust/weight of 20 to 25 percent appears reasonable. The corresponding TOGW reductions would be:

- 9 to 11 percent for the all-supersonic cruise mission
- 14 to 17 percent for the mission with 2,000-nautical-mile subsonic cruise segment overland

Although engine weight is only approximately 10 percent of TOGW, there is the potential for TOGW reductions of 10 percent or more from increasing engine thrust/weight. When combined with the SFC reduction, the potential TOGW reductions would be:

- 15 to 17 percent for the all-supersonic cruise mission
- 25 to 28 percent for the case with 2,000-nautical-mile subsonic cruise segment overland

GE and Aerojet TechSystems have addressed the technology needs and projections for their respective Mach 5.0 engines.

GE showed an SFC improvement of 0.5 percent for its variable cycle turbofan ramjet engine through control schedule optimization. GE provided projections of SFC improvements (5 percent subsonically, 2 percent at Mach 5.0) assuming better technology. These would be achieved through component efficiency increases, reductions in cooling air requirements, improvements in burner efficiency, and reductions in nozzle unburned air. Increased material temperature capability, reduced losses, and better heat transfer formed the bases for these projections. Projections of 20- to 25-percent improvement in Mach 5.0 engine thrust/weight appear reasonable through higher stage loadings and advanced materials. When combined, these data indicate potential TOGW reductions of:

- 16 to 18 percent for the all-supersonic cruise mission
- 33 to 36 percent for the case with 2,000-nautical-mile subsonic cruise segment overland

AIRPORTS AND THE ENVIRONMENT

Airports

Most, if not all of the world's international airports that are likely candidates for future HSCT service already experience DC-10 and 747 aircraft with larger versions forthcoming. Few new airports are expected in the future for several reasons. First, the very high cost; the new Osaka Airport is reported to cost in excess of $5 billion and the new Denver Airport at more than $2.5 billion. Second, the lack of public acceptance of new airports causes significant delays and has forced development in remote locations, less convenient for the traveler. And third, the flatter terrain is already developed leaving topographic areas inappropriate for airport development. For these reasons, new airports are not good solutions for HSCT operations.

Douglas has established the objective that the HSCT must be able to operate from existing airports located close to the centroid of demand. This way, the traveler will be facilitated by fast transportation from portal to portal. This necessitates compatible approach speeds, touchdown speeds, field lengths, and noise characteristics. The portions of the airport infrastructure that must accommodate the HSCT consist of the airfield, terminal area, and fueling facilities.

Three airfield characteristics will be affected: maneuvering space, clearance areas, and pavement strength. The overall length will present difficulties in maneuvering on existing taxiway-to-taxiway and runway-to-taxiway intersections and also in the terminal area. Figure 37 illustrates a characteristic comparison of the wide-body jets, the advanced subsonic transport, the Mach 3.2 and Mach 5.0 concepts. Both HSCTs present servicing difficulties due to the wing shape with the Mach 3.2 concept further disadvantaged due to door sill heights of 25 feet to 27 feet, which are significantly higher than current aircraft. Both the Mach 3.2 and Mach 5.0 concepts will require new fuel facilities, although LNG facilities are more complex and site demanding.

	MD-11	747-400	ADVANCED TECHNOLOGY SUBSONIC	MACH 3.2 (D3.2-3A)	MACH 5.0
FUEL	JP	JP	JP	TSJF	METHANE
SPAN (FT)	169.5	211.0	195.0	121.2	136.7
LENGTH (FT)	200.9	231.8	189.6	315.0	297.7
HEIGHT (FT)	57.8	60.2	62.5	60.5	49.0
TOGW (LB)	602.5	850.0	397.0	769.0	1,213.0

FIGURE 37. AIRCRAFT CHARACTERISTICS

Pilots maneuver their aircraft by maintaining the cockpit over the taxiway centerline at most ICAO airports. In the U.S., pilots maneuver by attempting to reduce the main gear track radius. If the nose gear is located significantly aft of the cockpit, pilots may prefer to use the cockpit-over-the-centerline technique. Use of an onboard closed-circuit television (CCTV) may solve the guidance visibility problems and by maneuvering the Mach 3.2 aircraft with the nose gear over the centerline, the fillet requirements may be no more extensive than that required for stretched versions of the MD-11. Worldwide category IIIC airport capability, together with nonvisual guidance to gates could result in nose gear-over-the-centerline maneuvering during zero-zero visibility conditions.

The only airfield clearance problem that may exist concerns close parallel runways (700 feet center-to-center), such as at Los Angeles. Under ICAO rules, the taxi holding line is 274.3 feet from the runway centerline, thus a 315-foot-long (Mach 3.2) aircraft will not be able to hold between the two runways without restricting operations.

The goal to not exceed loads of current aircraft determines the number of tires and their spacing of HSCT vehicle concepts. Further, the Mach 5.0 airplane will be restricted from current bridges and overhangs that have not been designed for aircraft weighing more than one million pounds.

TSJF used for the Mach 3.2 aircraft is assumed to involve special handling to control contamination based on engineering specifications regarding JP-7 fuel facilities. Therefore, new storage, distribution, and dispensing facilities will be required for the exclusive use of TSJF. Fueling and handling spills and leaks is similar to Jet A. LNG, (Mach 5.0 aircraft) will also require new storage, distribution, and dispensing facilities as well as an on-airport liquefaction facility requiring a large, dedicated ground area and a heat-exchange tower. LNG fueling procedures will differ from current by requiring the addition of a boiloff return line from the aircraft. Grounding the aircraft to prevent spark generation will be similar to subsonic aircraft.

Special training for TSJF deoxygenation or inerting, or handling LNG including leaks or spills will be required. Ground crew will use gloves for protection against cold LNG temperatures (−259°F).

Fluor Engineers and Air Products performed a study of airport fuel facility requirements comparing the costs of TSJF with LNG. Capital and operating costs of the fuel facility system(s) were developed and included in aircraft worth determinations.

Terminal gate facilities will undergo changes to accommodate the HSCT due to fuselage length and height. Most major terminal gate parking areas handle aircraft that are no longer than 231 feet with door sill heights up to 17.6 feet. Consequently, the HSCT will have to be angle parked, as illustrated in Figure 38, at existing gate areas modified for the very high door sill heights. As is shown in Figure 38, angle-parking does not require additional terminal frontage beyond that required for the 747-400. All aircraft servicing will require special terminal building and service equipment due to the high elevation of doors and access panels. Current loading bridges cannot be raised to the Mach 3.2 door sill heights because the bridge ramp would exceed the maximum 8-percent slope. HSCT passenger loading will probably take place from a third level added to the terminal/concourse building. The delta or arrow-wing planform makes it difficult to access mid-fuselage doors for servicing. A special, very tall galley servicing truck will be required because of (1) close proximity of the engine nozzles space and (2) the height of the fuselage.

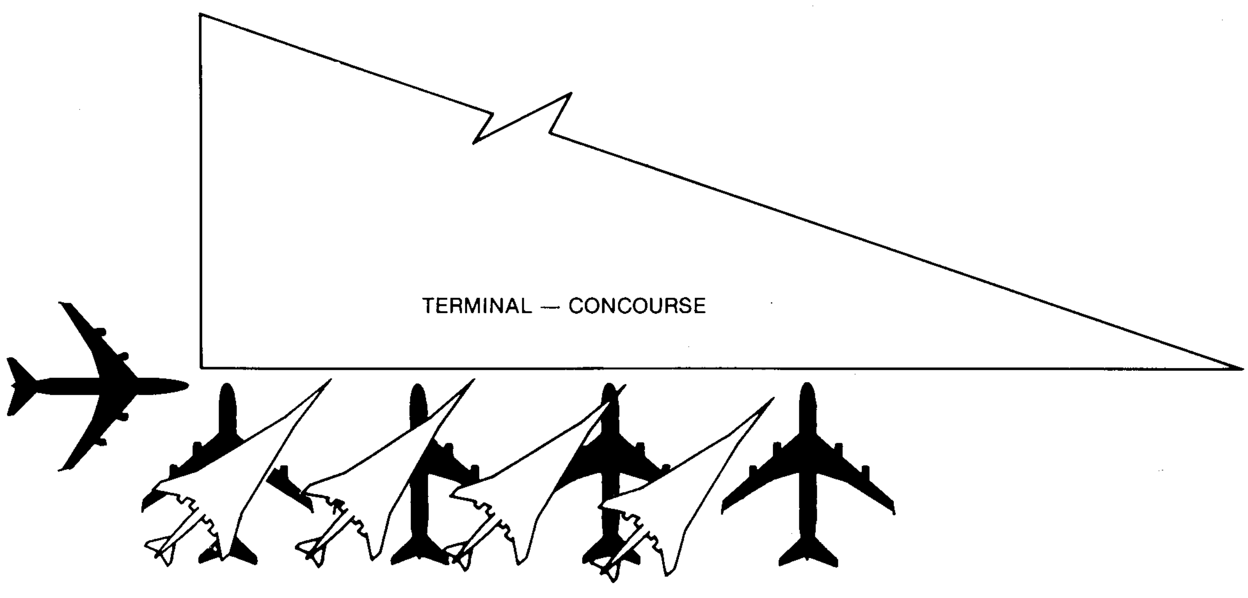


FIGURE 38. GATE PARKING

Aircraft servicing will almost exclusively be turnaround activities rather than quicker through-stop activities. Today's international flight turnaround scheduled time for high-capacity aircraft is 2 hours. Economic analyses indicate added benefit of shortened turnaround times for the HSCT. A goal of 1 hour has been established. Total time is projected at 75 minutes, utilizing automated self-test sequencing and by assuming that passengers can be onboard during the systems self-testing, then the turnaround time can be reduced by 10 minutes, which is close to the 1-hour goal. Discussions with the airlines have highlighted the desirability of achieving this goal.

Scheduled NAS Plan increases in automation of ATC navigation and communication equipment and procedures should provide efficient safe routing of all commercial aircraft including the HSCT. It is assumed that the HSCT will not have any special approach or departure priorities and as such will experience ground and approach delays equally with all other transport aircraft.

The following will enhance HSCT integration with the future ATC environment, reduce flight crew workload, and improve economic viability:

- Automatic separation assurance, threat-alert, and collision-avoidance
- Fuel Advisory Departures (FAD) to minimize engine time, fuel consumption, and airspace congestion
- Traffic flow metering and spacing
- Fuel-efficient flight through Automatic En Route ATC (AERA)
- Automated Dependent Surveillance (ADS) in lieu of flight crew reporting

Additionally, the HSCT must achieve international operational, regulatory, and political acceptability. The HSCT could use the Global Positioning System (GPS) effectively as an en route navigational service where current navigational aids over water are inadequate; high-altitude cruise of the HSCT will alleviate the subsonic en route airspace. Global acceptance of an HSCT crossing international borders and flying within international airspace must be obtained. Regulations regarding flights above the current level of positive-controlled airspace (above 60,000 feet) must be developed.

Expanded high-altitude global weather information will ensure safe and comfortable flight. Flight-time reductions will result in more reliable weather predictions, thus minimizing flight delays and rerouting, and favorably effect fuel-reserve planning.

Environment

Community Noise. The large majority of the subsonic fleet will be Stage 3 at the time the HSCT enters service. Hence, it was assumed that the HSCT also must meet FAR Part 36, Stage 3 noise certification requirements. The airlines generally agree that Stage 3 is an appropriate HSCT design goal. The airlines also believe that HSCT development will require international cooperation (e.g., within ICAO) to achieve an acceptable HSCT community noise standard. The public and regulatory agencies have more than 20 years' experience with Effective Perceived Noise Level (EPNL), and Douglas is of the opinion that EPNL should remain the certification noise metric.

Noise reduction concepts include: inverted velocity profile (4-6 EPNdB), suppressor (6-8 EPNdB), suppressor and ejector (7-15 EPNdB), thermal shield (2-4 EPNdB), and porous centerbody (2-5 EPNdB). Some of these concepts have been verified. However, the tests were not conducted at the higher HSCT jet temperatures and velocities and therefore, more tests are required to extend existing data bases. Combinations of these concepts could provide 10 to 20 dB noise attenuation.

Noise level estimates at the FAR Part 36 reference locations, including the effects of the inverted velocity profile (IVP), a jet noise suppressor, and a treated ejector are shown in Figure 39. These aircraft are sized to meet the 6,500-nautical-mile range goal as previously discussed, but fail to meet the FAR 36, Stage 3 noise regulation. The ejector may not be compatible with the Mach 5.0 concept SERN. Both HSCT concepts show the largest exceedance of Stage 3 requirements at the sideline reference location.

The Part 36 sideline noise estimates have assumed 12-dB and 5-dB suppression for the VSCE (Mach 3.2) and VCE (Mach 5.0) concepts, respectively. The sideline noise levels for the Mach 3.2 concept exceed the Stage 3 requirements by 9.5 dB. The Mach 5.0 concept sideline noise is 13 dB above the requirement. An additional 2- to 3-dB reduction in sideline noise could be achieved with operational procedures where engine thrust is reduced early in the flight path.

P&W predicted sideline noise for both an unsuppressed VSCE and with an outer stream jet noise suppressor. Variable fan and core jet areas are key features of the VSCE which enable "high flowing" the engine. The major noise sources are the jet (mixing plus shock) noise and the duct burner combustion noise. P&W estimated a 4-dB benefit from a circumferential Thermal Acoustic Shield. However, jet noise dominated VSCE are projected to exceed the Stage 3 sideline noise limit.

For engines dominated at takeoff powers by jet noise, one means of reducing sideline noise is to oversize the engines (increased airflow, diameter, and thrust) and operate them at a lower relative power takeoff condition. The noise penalty associated with increased size is more than offset by the attendant reduced jet velocity. However, the larger engines are heavier and do not operate at optimal power in the cruise regime, thus having increased fuel burn and either an aircraft takeoff gross weight penalty or range penalty. Increasing the Mach 3.2 engine size by 110 percent reduced the sideline noise by up to 19 dB, but resulted in an aircraft range loss of 1,400 nautical miles. An aerodynamic improvement of 20 percent reduced takeoff and approach noise levels, but did not affect sideline noise. For the Mach 5.0 configuration, decreasing the sideline noise by 9 dB resulted in oversizing the engine by 164 percent.

GE made sideline noise estimates for the Mach 5.0 concept with a 2D-CD wedge SERN nozzle of 112 dB, or ~ 9 dB over the Stage 3 limit of 103.0 dB.

CONCEPT	ENGINE	TOGW (LB)	SIDELINE	TAKEOFF (CUTBACK)	APPROACH
D-3.2-3A	P&W VSCE	769,000	112 (−12)	110 (−8)	106 (−6)
STAGE 3 REQUIREMENTS			102.5	105.4	105
D-5.0-15A	GE VCE	1,213,000	116 (−5)	N/A	N/A
STAGE 3 REQUIREMENTS			103	106	105
CONCORDE	OLYMPUS 593	385,000	112.0	119.5	117.0

NOTE: ABOVE NOISE ESTIMATES DO NOT INCLUDE SHOCK CELL, DUCT BURNER, OR TURBOMACHINERY NOISE

( ) SUPPRESSION ASSUMED EXCLUDING IVP

INCLUDES INVERTED VELOCITY PROFILE PLUS SUPPRESSION DEVICES

FIGURE 39. ESTIMATED FAR PART 36 NOISE LEVELS (EPNdB)

The impact the Mach 3.2 concept would have on community noise can be gauged on the 100-EPNdB (approximately 87-dB(A)) noise contours using the Part 36 takeoff procedure in comparison to those for a typical long-haul subsonic airplane (Figure 40). This shows the HSCT, with the IVP and suppression devices, to be considerably noisier than the 747-200; 2.2 square miles for the 747-200, compared to 8.7 square miles for the HSCT. In order for the Mach 3.2 concept to be comparable, a further noise reduction of 8 dB and 7 dB at sideline and takeoff, respectively, is required and should be the basis of further innovative research. The effect of a 2:1 oversizing of the unsuppressed engine results in reducing the 100-EPNdB contour area to 3.5 square miles. As stated above, oversizing the engine results in an unacceptable aircraft range reduction (more than 1,000 miles). The addition of a noise-suppression device would reduce the contour areas by approximately 50 percent. The total HSCT contour area could be reduced in size by optimizing the takeoff procedure for minimum area rather than flying the Part 36 cutback procedure.

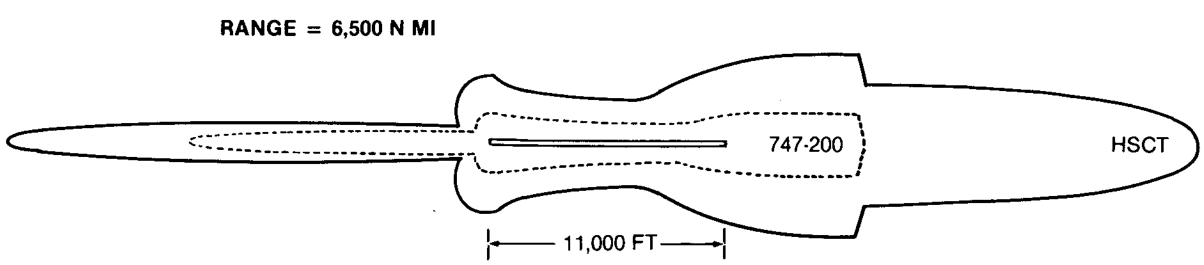


FIGURE 40. MACH 3.2 CONCEPT 100 EPNdB NOISE CONTOURS

Sonic Boom. Sonic booms caused by supersonic aircraft exhibit vastly different acoustic characteristics than subsonic aircraft flyover noise. A sonic boom is a high-energy, impulsive sound that generates a large subaudible, low-frequency component. Sonic boom levels are typically measured by peak or maximum overpressure. However, human response to sonic booms is a function of the entire waveshape, not just the peak overpressure (References 5 and 6). Acceptance of individual sonic boom events is best measured with a loudness descriptor. The best metric appears to be Stevens (Mark VII) model for Perceived Loudness Level in PLdB (Reference 7) because of its sensitivity to changes in waveform shape and inclusive research.

Listeners in a variety of conditions and locations, both indoors and outdoors, may not be sensitive to the fine changes in waveform shape to which a loudness descriptor is sensitive. Community response to multiple daily sonic boom events is best measured with a Day-Night Average C-Weighted Sound Exposure Level ($L_{C_{dn}}$)

(Reference 8). This metric is based on Oklahoma City tests and verified by the Army Construction Engineering Research Laboratory (Reference 9). Based on this work, Douglas has selected sonic boom design criteria of a Perceived Loudness Level of 90 PLdB and a C-Weighted Sound Exposure Level of 102 dB. However, research on human response to sonic booms at this level must be conducted to verify that these levels are acceptable.

Sonic boom waveforms for HSCT configurations were predicted using two different methods: (1) The sonic boom for the Mach 3.2 concept was calculated using MDBOOM which generates volume and lift distributions along the Mach cutting planes. Atmospheric propagation using Thomas' method (Reference 10) yields sonic boom waveforms on the ground. (2) A nonlinear numerical code was used for the Mach 5.0 concept in view of the strong shocks.

The sonic boom waveforms and their corresponding response metrics are shown for each configuration at the beginning and end of cruise in Figure 41. As can be seen, the sonic boom design criteria are exceeded even at the end of cruise. Except for the climb out, the most critical sonic boom occurs at the beginning of cruise directly under the flight track. As the aircraft decreases in weight and increases in altitude over the course of a mission, the sonic boom levels drop significantly. At Mach 3.2, the beginning to end-of-cruise level drops from 1.9 psf to 1.2 psf, and at Mach 5.0 the level drops from 2.0 psf to 1.6 psf. To put these boom levels into perspective relative to current aircraft, the Concorde sonic boom overpressure is 2.0 psf and is banned from overland flight supersonically. The HSCT flies at Mach 3.2 relative to the Concorde at Mach 2 and carries three times the payload at twice the range at sonic boom levels that are slightly less. The aircraft which cannot meet boom design goals and fly supersonically overland at the beginning of cruise may be able to do so at some point along its flight path.

HUMAN RESPONSE METRICS

	3.2	5.0
P, PLdB	102.1	100.7
L_{CE}, dB	107.4	106.1
ΔP MAX, PSF	1.9	2.0

HUMAN RESPONSE METRICS

	3.2	5.0
P, PLdB	95.9	97.2
L_{CE}, dB	103.0	103.8
ΔP MAX, PSF	1.2	1.6

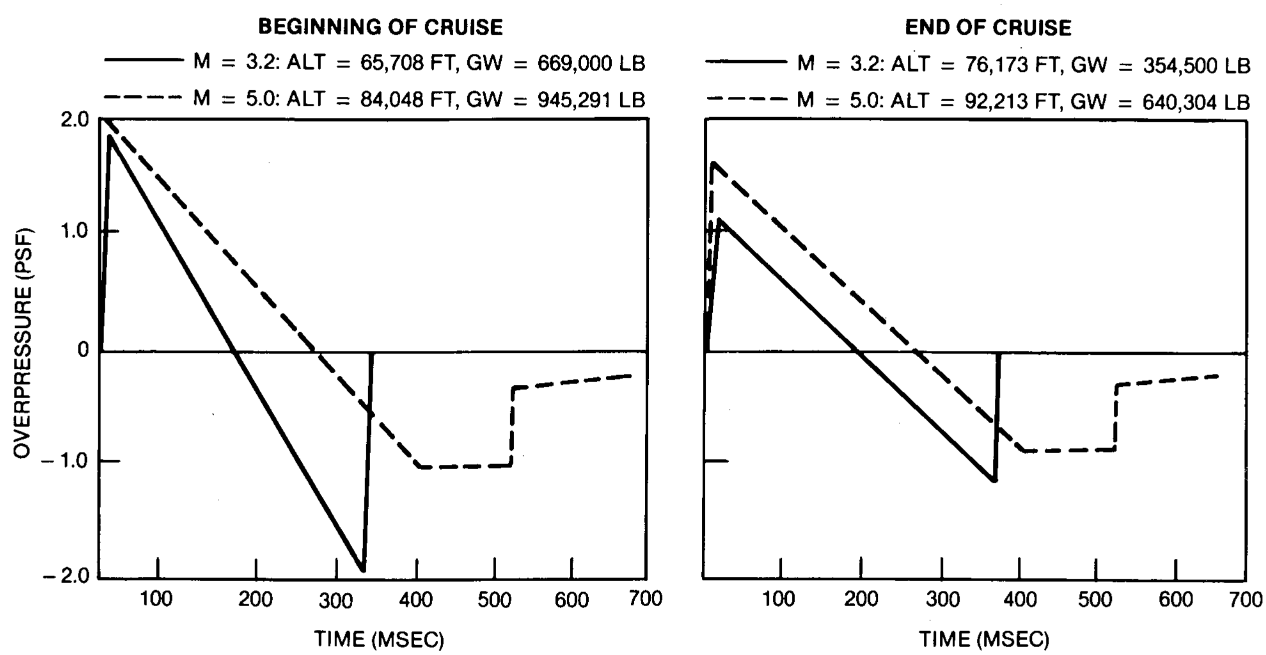


FIGURE 41. SONIC BOOM WAVEFORMS

The sonic boom off-track carpets at the beginning of cruise for the Mach 3.2 and Mach 5.0 concepts are shown in Figures 42 and 43, respectively. Off-track boom overpressures decrease significantly; more than one-half of the boom carpet for the Mach 3.2 concept experiences an overpressure of less than 1.0 psf, even though the centerline overpressure is 1.9 psf. The Mach 5.0 concept off-track boom overpressures decay at a slower rate. The large width of the boom corridor (52 miles at Mach 3.2, 65 miles at Mach 5.0) indicates that the off-track boom levels are important and need to be considered for environmental impact.

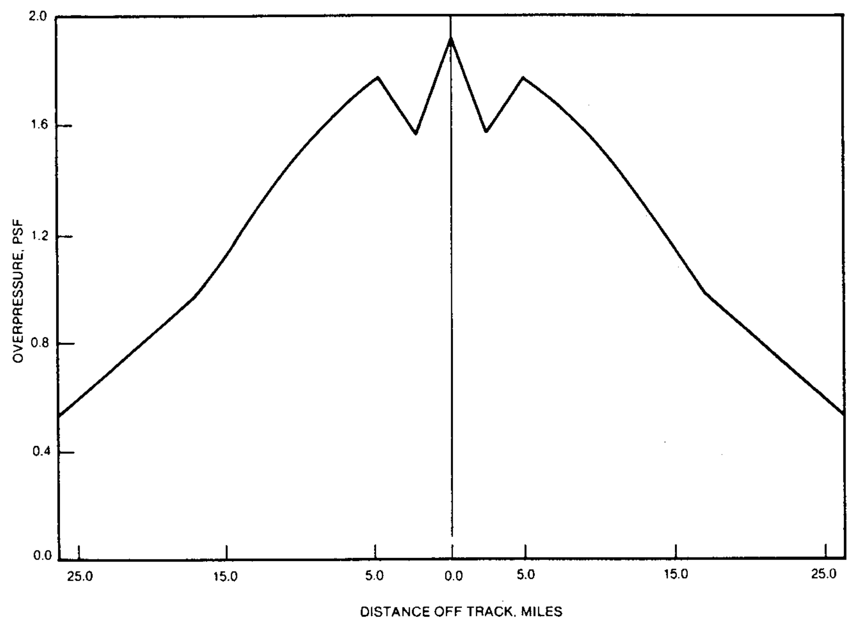


FIGURE 42. MACH 3.2 CONCEPT SONIC BOOM OVERPRESSURES ON THE GROUND

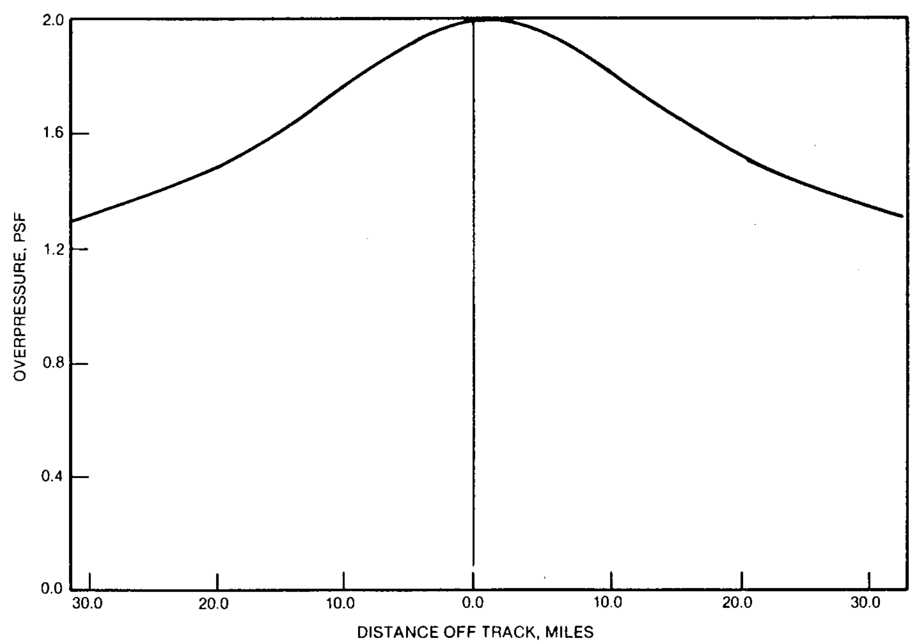


FIGURE 43. MACH 5.0 CONCEPT SONIC BOOM OVERPRESSURES ON THE GROUND

Sonic boom minimization can be approached from two different perspectives: (1) Design and operate the aircraft such that the shock strength, and hence peak overpressure at the ground, is minimized. This results in aerodynamically slender, long vehicles. (2) Sonic boom shaping which involves creating sonic boom waveshapes with minimum shock strengths and reduced high-frequency energy. This method is considerably more difficult from a design standpoint and will result in aircraft configurations that depart considerably from aerodynamically optimized designs.

Various modifications to the baseline Mach 3.2 concept were evaluated. The most promising configuration involved a modification and extension of the wing and resulted in a 20-percent reduction in overpressure. A comparison of this configuration with the baseline is shown in Figure 44. Further, a 20-percent reduction in overpressure can be obtained by increasing the cruise altitude from 65,000 to 85,000 feet. A 20-percent reduction in overpressure is available through a 30-percent weight reduction. These results indicate that a combination of careful aircraft shaping, and high-altitude cruise weight reduction, may lead to far field N-waves of 1.0 psf or less. The best prospects for sonic boom minimization appear to be in a low-drag, long, slender, high-altitude aircraft. The combination of shaping, weight reduction, and increased altitude have potential for as much as a 60-percent reduction over current levels. This corresponds to an overpressure of approximately 0.8 psf, which is in the range of potentially acceptable levels.

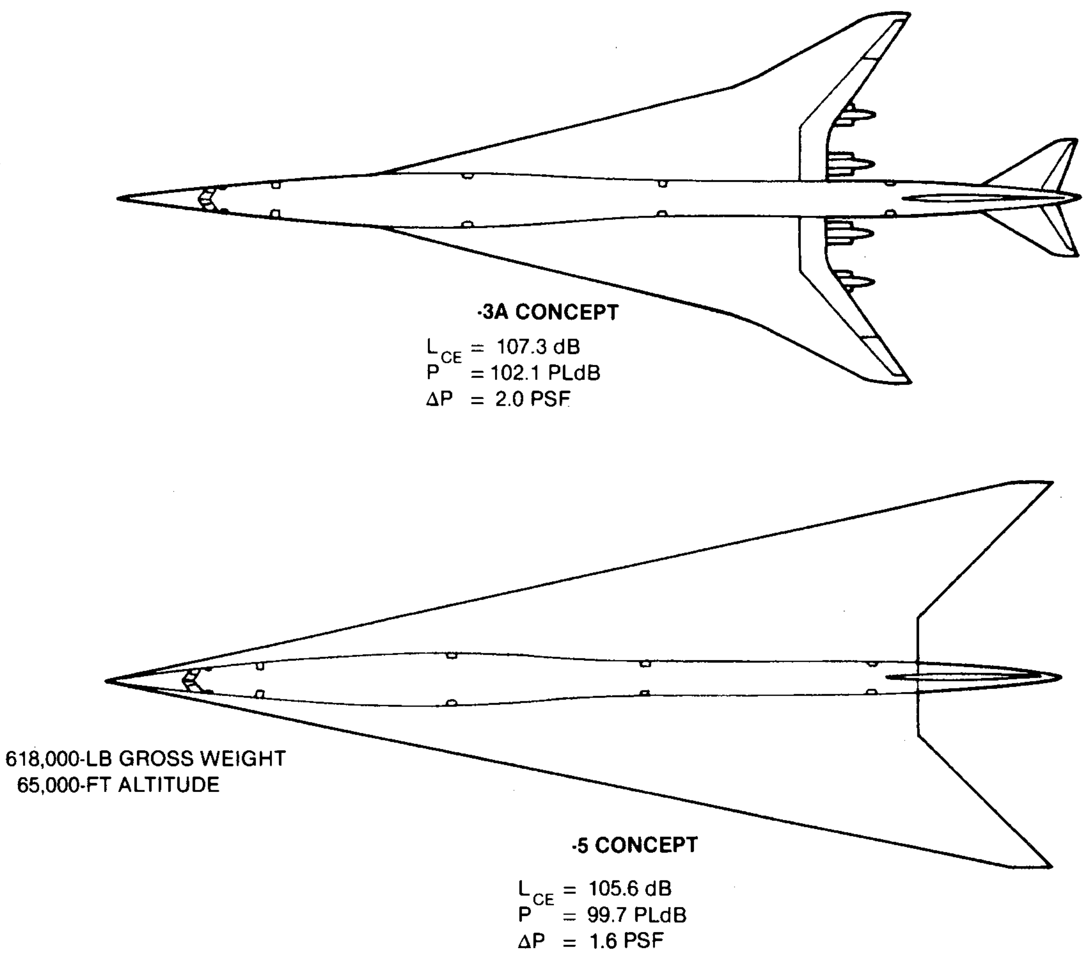


FIGURE 44. MACH 3.2 SONIC BOOM MINIMIZATION

Emissions. Early in the HSCT study, atmospheric ozone was defined as an important element of environmental compatibility. As the study progressed, ozone concentration, atmospheric models, chemistry interactions, dynamics, HSCT characteristics, and operational factors (e.g., HSCT fleet size, altitude, geographical markets) evolved into a process for projection of long-term effects on ozone and identification of technology drivers and goals. NASA focused on creditable atmospheric models that would be available to interface with study activities to evaluate HSCT concepts in the process of determining technology requirements.

One of the key goals of the propulsion system studies was achieving low levels of NOx emissions while maintaining desired levels of thrust and efficiency. Current technology engines do not offer the prospects for environmentally acceptable HSCTs from the emissions standpoint. Additional technology must be developed to reduce the magnitude of harmful combustion products.

Both GE and P&W, under subcontracts, conducted studies of the impact of advanced technology combustors on engine emissions and engine performance. The engine exhaust products — specifically the nitrogen oxides — were estimated at supersonic cruise conditions because oxides of nitrogen emissions are most critical at high-altitude flight condition. Here, the combustor inlet temperatures are at their highest level. Projections were made of the exhaust gas composition and incremental engine performance for progressively more advanced technology combustor systems relative to an engine with current combustor technology levels.

The reference engine for the Mach 3.2 concept is the P&W VSCE operating on TSJF. Many of the exhaust gas constituents are dependent only on the composition of the fuel. These include oxides of sulphur, trace metals, water vapor and carbon dioxide. Emissions of carbon monoxide, unburned hydrocarbons, oxides of nitrogen and smoke were estimated. The P&W VSCE with a near-term technology combustor system was projected to have NOx Emissions Index level of 39.5 — significantly above estimates for the 1971 U.S. SST.

Advanced combustion technology studies identified a rich-burn quick-quench (RB/QQ) concept for the main burner. In this concept all of the fuel is consumed in a combustion zone having a very rich mixture; the temperature is moderate and the formation rate of oxides of nitrogen is low. The combustion products pass through a second reaction zone in which the mixture is lean and temperatures are sufficiently high to effect combustion, but low enough to control the formation of oxides of nitrogen. The rich-to-lean mixture transition is accomplished in the quick-quench section between these zones. Projections indicate substantially lower NOx emissions — 12.1 — than the current technology main burner. Combustor complexity factors include length requirements, variable geometry features, fuel preparation, and the need for novel material and/or cooling concepts for the liner in the rich zone.

A more advanced, lean, premixed, prevaporized (PM/PV) combustion system is the most aggressive technology identified. This concept achieves very low NOx by not only lean burning but also by avoiding any locally rich regions. This is accomplished by prevaporizing the fuel to a homogeneous mixture for the combustion process. This requires variable geometry of air passages to control the fuel/air ratio. The fuel must be heated to about 800°F before entering the combustor. A practical combustor using prevaporized liquid fuel has never been demonstrated.

The estimated emissions characteristics of the P&W VSCE engine with the near-term and advanced technology burners are presented in Figure 45. The total oxides of nitrogen emissions at supersonic cruise with a PM/PV main combustor are less than one-fourth that of the engine with the current technology main burner (emissions index of 8.7 versus 39.5). Adding a lean, premixed, prevaporized duct burner reduces the supersonic cruise NOx emissions to 15 percent of current technology or 6.1. A combustor concept projected to produce the lowest NOx emissions is considered to be a very high risk approach. Substantial additional development is required to produce viable prevaporizing and premixing systems for use with liquid fuels and the variable geometry airflow systems required for stochiometry. There are also fundamental risk elements such as preignition and flashback in the premixing passages.

Differences in engine performance with the three main burner concepts are projected to be extremely small with combustion efficiency above 99 percent. Some minor variants in specific fuel consumption are projected for the climb phase of the mission.

Engine emissions were processed through market models leading to analysis of ozone dynamics. One representative city-pair was selected from each of the ten international traffic regions; altitude, fuel burn, and latitude profiles were determined. Engine exhaust parameters provided by the engine companies allowed conversion of the fuel burns into quantifiable products of combustion. The fuel burned in altitude levels and latitude bands for Mach 3.2 concept are illustrated in Figure 46; correspondingly, fleet models of fuel burn and emissions products for the Mach 5.0 concept were developed. These data serve as inputs to atmospheric chemistry models executed by agencies under direct contract to NASA to determine the impact on the atmosphere. The results of these analyses will provide guidance and direction for follow-on engine technology development and specific engine emission requirements.

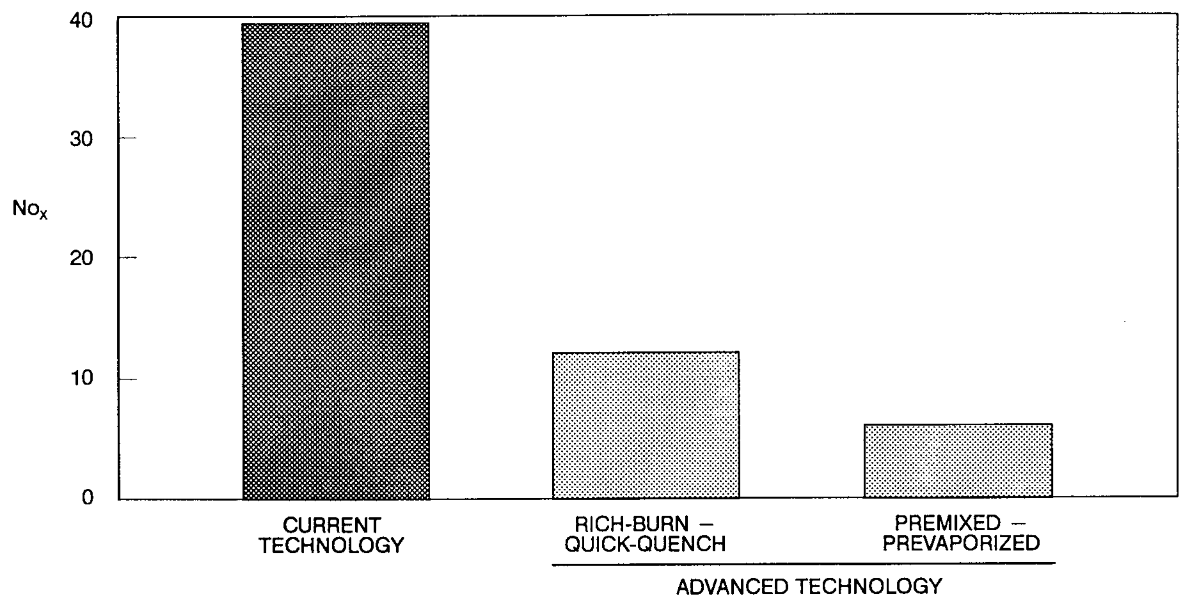


FIGURE 45. MACH 3.2 ENGINE MAIN BURNER EMISSIONS INDEX

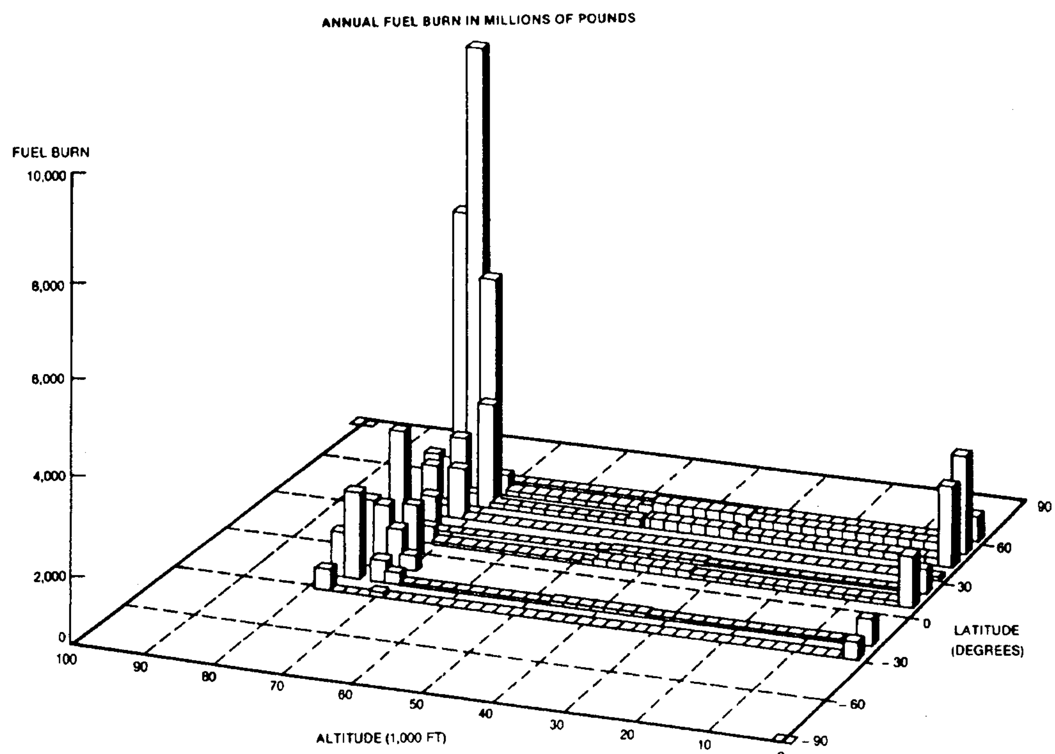


FIGURE 46. MACH 3.2 ANNUAL FUEL BURN

CONCLUSIONS

MARKET

1. Market projections for the 2000 to 2025 time period indicate sufficient passenger traffic for ranges beyond 2,000 nautical miles to support a fleet of economically viable and environmentally compatible high-speed commercial transports.
2. The fleet size that will satisfy these traffic projections depends on utilization, productivity, and fare premium. HSCT fleet needs of 300 aircraft in the year 2000 could grow to 1,500 or more 300-seat aircraft by 2025.
3. Between 2000 and 2025, the Pacific Rim will become the major traffic region, thus leading to a design-range objective of 6,500 nautical miles.
4. For high-speed commercial service, an increase in ticket price over competing subsonic service that would be acceptable to the public would enhance the economic viability of HSCT. However, the price sensitivity for coach passengers is much greater than for first class. A fare increase as small as 10 to 20 percent above the subsonic level would sharply erode the coach passenger market.
5. Economic viability places emphasis on environmentally acceptable supersonic flight over land. The constraint of no supersonic flight over land reduces potential aircraft productivity (i.e., seat-mile per year) by 7 to 28 percent for the Mach 3.2 concept.

CRUISE SPEED

1. Aircraft productivity increases with cruise speed up to about Mach 5 to Mach 6 for market applications ranging from 2,000 to 6,500 nautical miles. Above this point, the relative significance of cruise speed diminishes, and productivity is virtually constant.
2. Design mission gross weights increase with cruise Mach number and, correspondingly, advanced technology requirements are greater, possibly resulting in later readiness dates.
3. LNG applications at Mach 5.0 do not result in competitive opportunities since liquid methane's energy content falls short of requirements. The liquid hydrogen aircraft (Mach 6) are not competitive due to the high fuel cost.
4. Economic studies of the Mach 3.2 concept suggest viability could be achieved through modest fare premiums and successful research, providing gross weight reductions and propulsive efficiency improvements as well as operational improvements.

ENVIRONMENTAL CONSIDERATIONS

1. Advanced engine technology has been identified that offers the potential for reductions in oxides of nitrogen to 15 percent of current levels.
2. FAR 36, Stage 3 noise certification requirements for a design range of 6,500 nautical miles cannot be met with technology projections of this study. Oversizing engines to reduce the noise causes unacceptable losses in mission range.
3. Concepts presented in this study are estimated to be capable of meeting performance objectives — 300 passengers/6,500 nautical miles — with slightly lower sonic boom characteristics than the Concorde (at 100 passengers/3,200 nautical miles). However, the HSCT concepts fall short of meeting the tentatively selected metric goals.
4. Sonic boom acceptability criteria are necessary to fully determine conditions of environmental compliance.

U.S. ECONOMY

1. From the standpoint of the U.S. economy, a 1,000-unit HSCT program would create a peak-employment gain of more than 400,000 jobs. This translates into a projected $500 billion increase in GNP and represents an improvement in the balance of trade of more than $100 billion.

RECOMMENDATIONS

RESEARCH AND TECHNOLOGY NEEDS

The HSCT study was primarily an assessment of technology in terms of potential commercial value with a continuing emphasis on narrowing the range of Mach number design options. The purpose of the study is to assist NASA to plan follow-on research and technology activities. Early in Phase I it was concluded that current technology was insufficient to support a production development program. Throughout the study, technology needs were monitored as part of the HSCT concept definition process.

A compilation of insights which focuses on the Mach range suited to a kerosene-fueled HSCT is presented. The range of interest extended to Mach 3.2 using a kerosene-based fuel, which has higher thermal stability characteristics than the currently available kerosene-based jet fuel (Jet A).

Airframe technology needs are grouped in three categories: environmental, key performance technologies, and integration and supporting technologies (Figure 47). These are based on relative priorities, significance, and program logic. The time period is predicated on a year 2000 to 2010 HSCT certification (kerosene-based fuel) with configuration development commencing in 1996-97. Research directed toward solution to the environmental concerns is of the highest priority. It must be emphasized, however, that other technologies such as materials and propulsion systems must be worked in the near term due to affect on HSCT weight which is a factor in environmental compatibility.

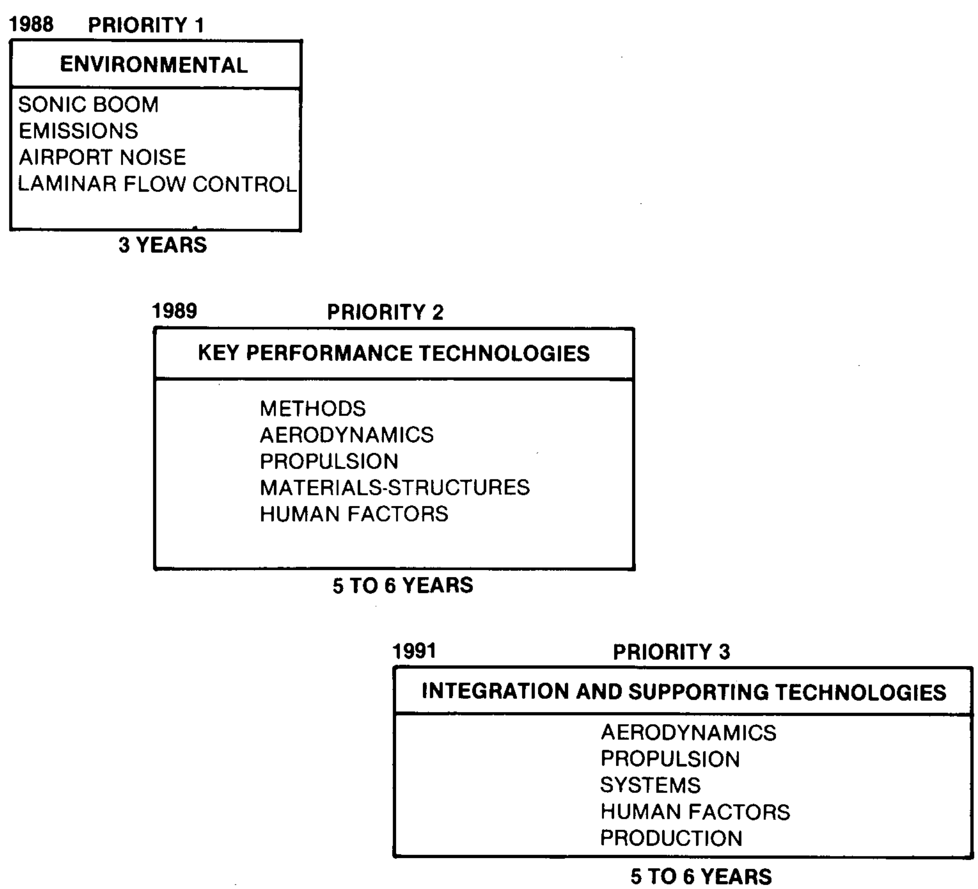


FIGURE 47. TECHNOLOGY PLAN

REFERENCES

1. NASA Report No. CR-165723, Technology Study for Advanced Supersonic Cruise Vehicles, June 1981.
2. Morris, R. F., Brewer, G. D., NASA Report No. CR158926, Hypersonic Cruise Aircraft Propulsion Integration Study, Volumes I and II, September 1979.
3. Cubbage, J. M. and Kirkham, F. S., NASA Report No. TN D-6060, Investigation of Engine-Exhaust-Airframe Interference on a Cruise Vehicle at Mach 6, January 1971.
4. Darden, C. M., NASA Report No. TP-1348, Sonic-Boom Minimization with Nose-Bluntness Relaxation, January 1979.
5. Zepler, E. E., Harvel, J.R.P., The Loudness of Sonic Booms and Other Impulsive Sounds, J. Sound Vib., 2(3), pp. 249-256, 1965.
6. Johnson, D. R., Robinson, D. W., The Subjective Evaluation of Sonic Bangs, Acoustica, 18(5), 1967.
7. Stevens, S. S., Perceived Level of Noise by Mark VII and Decibels (E), JASA 51 (2) (Part 2), pp. 575-601, 1972.
8. Borsky, P. N., Community Reactions to Sonic Booms in the Oklahoma City Area, National Opinion Research Center, AMRL-TR-65-37, 1965.
9. Schomer, P. D., Neathammer, R. D., Community Reaction to Impulsive Noise: A Final 10-Year Research Summary, U.S. Army Construction Engineering Research Laboratory, TR N-162, 1985.
10. Thomas, C. L., Extrapolation of Sonic Boom Pressure Signatures by the Waveform Parameter Method, NASA TN D-6832, June 1972.

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Final Report – Summary

16. Abstract

A systems study to identify the economic potential for a high-speed commercial transport considered technology, market characteristics, airport infrastructure, and environmental issues. Market forecasts indicate a need for HSCT service in the 2000/2010 time frame conditioned on economic viability and environmental acceptability. Design requirements focused on a 300-passenger, 3-class service, and a 6,500-nautical-mile range, based on accelerated growth of the Pacific region. The need for compatibility with existing airports was assumed. Mach numbers between 2 and 25 were examined in conjunction with the appropriate propulsion systems, fuels, structural materials, and thermal management systems. Aircraft productivity was a key parameter, with aircraft worth rather than aircraft price being the airline-oriented figure of merit. It was determined that Mach 3.2 (TSJF) would have superior characteristics to Mach 5.0 (LNG) and recommended that the next-generation high-speed commercial transport aircraft use a kerosene fuel. The sensitivity of aircraft performance and economics to environmental constraints (e.g., sonic boom, engine emissions, and airport/community noise) was identified together with key technologies. In all, current technology is not adequate to produce viable HSCTs for the world marketplace. Technological advancements must be achieved to meet environmental requirements. (These requirements are as yet undetermined for sonic boom and engine emissions). High priority is assigned to reducing aircraft gross weight which benefits both economics and environmental aspects. Specific technology requirements were identified and national economic benefits projected.

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